Railway Ground Hazard

RESEARCH PROGRAM

TP 14607E

Ground Penetrating Radar Investigation of Ballast on the CN and CP Rail Lines Near Ashcroft, British Columbia

Prepared for
Railway Ground Hazard Research Program

By
Associated Mining Consultants Ltd.

This study is part of the **Railway Ground Hazard Research Program**, an initiative of Canadian railways, federal agencies, universities and other stakeholders to develop risk management solutions to improve safety and reduce losses from ground hazard incidents on Canadian railways.

Partners in the Railway Ground Hazard Research Program are:

Transport Canada

Natural Resources Canada

Canadian National Railway

Canadian Pacific Railway

University of Alberta

Queen's University

TP 14607E

Ground Penetrating Radar Investigation of Ballast on the CN and CP Rail Lines Near Ashcroft, British Columbia

Prepared for
Railway Ground Hazard Research Program

By
Associated Mining Consultants Ltd.

June 2006

2007-01456/

TP 14607E

Ground Penetrating Radar Investigation of Ballast on the CN and CP Rail Lines Near Ashcroft, British Columbia

by

David Butler
Jane Dawson

Associated Mining Consultants Ltd.

June 2006

NOTICES

This report reflects the views of the authors and not necessarily those of Transport Canada, Natural Resources Canada, or the co-sponsoring organizations.

Neither Transport Canada nor Natural Resources Canada endorses products or manufacturers. Trade or manufacturers names appear in this report only because they are essential to its objectives.

Since some of the accepted measures in the industry are imperial, metric measures are not always used in this report.

Un sommaire français se trouve avant la table des matières.

RESEARCH PARTNERS
Railway Ground Hazard Research Program

Transport Canada

Natural Resources Canada

Canadian National Railway

Canadian Pacific Railway

University of Alberta

Queen's University

© 2006 TRANSPORT CANADA

Transport Canada / Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No.	2. Project No.	3. Recipient's Catalogue No.
TP 14607E	5556	

4. Title and Subtitle	5. Publication Date
Ground Penetrating Radar Investigation of Ballast on the CN and CP Rail Lines Near Ashcroft, British Columbia	June 2006
	6. Performing Organization Document No.
7. Author(s)	8. Transport Canada File No.
Dave Butler and Jane Dawson	2450-DP14
9. Performing Organization Name and Address	10. PWGSC File No.
Associated Mining Consultants Ltd. 4940 Canada Way Suite 300 Burnaby, British Columbia V5G 4M5	MTB-4-01080
	11. PWGSC or Transport Canada Contract No.
	T8200-044513/001/MTB
12. Sponsoring Agency Name and Address	13. Type of Publication and Period Covered
Transportation Development Centre (TDC) 800 René Lévesque Blvd. West Suite 600 Montreal, Quebec H3B 1X9	Final
	14. Project Officer
	Paul Lemay

15. Supplementary Notes (Funding programs, titles of related publications, etc.)

Co-sponsored by the partners of the Railway Ground Hazard Research Program: Natural Resources Canada, Canadian National Railway, Canadian Pacific Railway, University of Alberta, and Queen's University.

16. Abstract

This report details the work done to test the effectiveness of ground penetrating radar (GPR) as a tool to map variations in the thickness and quality of railway ballast and subgrade.

The first part of the survey tested a section of Canadian Pacific Railway (CPR) track near Ashcroft, British Columbia using several antennas to determine which was most effective. A subsequent production survey on the CPR track focused on data collection with 250 and 500 MHz antennas, as these had been shown to be most effective. A third survey along Canadian National (CN) track near Ashcroft, B.C. collected data using only the 250 MHz antennas.

Ballast and sub-ballast boundaries were identifiable along some sections of track. Test pit data were not sufficient to determine whether observed variations in the character of GPR reflections relate to ballast quality.

From a detailed evaluation of the data it was concluded that the 250 MHz antennas were the most effective for identifying ballast and sub-ballast boundaries. Antennas should be placed as close to the rail bed as safely possible. It was further recommended that for future surveys data be collected at walking speed to ensure data are collected directly over ballast in between rail ties.

17. Key Words	18. Distribution Statement
Ground penetrating radar, GPR, railway hazard, ballast	Limited number of print copies available from the Transportation Development Centre. Also available online at www.tc.gc.ca/tdc/menu.htm

19. Security Classification (of this publication)	20. Security Classification (of this page)	21. Declassification (date)	22. No. of Pages	23. Price
Unclassified	Unclassified	—	viii, 16, app.	Shipping/ Handling

Transports Canada Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. N° de la publication de Transports Canada	2. N° de l'étude	3. N° de catalogue du destinataire
TP 14607E	5556	

4. Titre et sous-titre	5. Date de la publication
Ground Penetrating Radar Investigation of Ballast on the CN and CP Rail Lines Near Ashcroft, British Columbia	Juin 2006
	6. N° de document de l'organisme exécutant

7. Auteur(s)	8. N° de dossier - Transports Canada
Dave Butler et Jane Dawson	2450-DP14

9. Nom et adresse de l'organisme exécutant	10. N° de dossier - TPSGC
Associated Mining Consultants Ltd. 4940 Canada Way Suite 300 Burnaby, British Columbia V5G 4M5	MTB-4-01080
	11. N° de contrat - TPSGC ou Transports Canada
	T8200-044513/001/MTB

12. Nom et adresse de l'organisme parrain	13. Genre de publication et période visée
Centre de développement des transports (CDT) 800, boul. René-Lévesque Ouest Bureau 600 Montréal (Québec) H3B 1X9	Final
	14. Agent de projet
	Paul Lemay

15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)

Coparrainé par les partenaires du Programme de recherche sur les risques géologiques en transport ferroviaire : Ressources naturelles Canada, Canadien National, Canadien Pacifique, Université de l'Alberta et l'Université Queen's.

16. Résumé

Ce rapport décrit les travaux réalisés pour vérifier l'efficacité du radar pénétrant (GPR, *ground penetrating radar*) en tant qu'outil pour cartographier les variations d'épaisseur et de qualité du ballast et de la sous-couche d'une voie ferrée.

Dans un premier temps, on a essayé plusieurs antennes sur un tronçon de la voie du Canadien Pacifique (CP) près d'Ashcroft, en Colombie-Britannique, afin de déterminer laquelle était la plus efficace. Puis, une investigation a été faite de la voie du CP au moyen d'antennes 250 et 500 MHz, car ce sont ces fréquences qui s'étaient révélées les plus efficaces. Une troisième étude a eu lieu sur la voie du Canadien National (CN) près d'Ashcroft, C.-B., cette fois uniquement à l'aide d'antennes 250 MHz.

Il a été possible de distinguer l'interface entre le ballast et la sous-couche le long de certains tronçons de la voie. Les données des fosses d'essai n'étaient pas suffisantes pour que l'on puisse déterminer si les variations observées dans la nature des réflexions du GPR étaient fonction de la qualité du ballast.

Par suite d'une évaluation approfondie des données, il a été conclu que les antennes 250 MHz étaient les plus efficaces pour discerner l'interface séparant le ballast et la sous-couche. Les antennes doivent être placées aussi près de l'assiette des rails que la sécurité le permet. Il a aussi été recommandé que pour les études futures, les données soient colligées à la vitesse de marche, pour faire en sorte que les données soient colligées directement au-dessus du ballast, entre les traverses.

17. Mots clés	18. Diffusion
Radar pénétrant, GPR, chemin de fer présentant un danger, ballast	Le Centre de développement des transports dispose d'un nombre limité d'exemplaires imprimés. Disponible également en ligne à www.tc.gc.ca/cdt/menu.htm

19. Classification de sécurité (de cette publication)	20. Classification de sécurité (de cette page)	21. Déclassification (date)	22. Nombre de pages	23. Prix
Non classifiée	Non classifiée	—	viii, 16, ann.	Port et manutention

SUMMARY

Railway companies require a rapid means of identifying track with a history of integrity problems. The main objective of this study was to determine the effectiveness of ground penetrating radar (GPR) as a tool to map variations in the thickness and quality of railway ballast and sub-grade.

A GPR survey was conducted along selected Canadian National (CN) and Canadian Pacific Railway (CPR) rail lines south of Ashcroft, British Columbia. Three different antenna frequencies were used: 250, 500 and 800 MHz. The antennas were mounted behind a vehicle and data collected between the rails. In total, approximately 26 miles of data were collected.

An analysis of the survey parameters was carried out to determine most effective antenna frequency, height of antennas above the ballast, speed of data acquisition, and processing streams.

An antenna frequency of 250 MHz provided the best results in the 1 to 2 m target depth and is recommended for use in high-speed reconnaissance surveys. Antennas of 500 MHz are recommended for low-speed detail surveys.

The height above the ballast is critical for good coupling of the antennas with the ground. The antennas should be as close as practically possible, usually in the order of 5 cm, to the ballast. In addition, it is recommended that a purpose-built trailer hitch mounted platform be constructed for use in rail bed surveys. This would ensure consistent location of the antennas with respect to the rails and ballast.

The ideal speed of acquisition is a walking speed. The higher lateral resolution provided by a slower survey will ensure data are collected directly over the ballast in between railway ties.

The ideal processing stream includes stacking, band-pass filtering, background removal, time-varying gain, horizontal smoothing and correction to time zero.

Ballast and sub-ballast boundaries were identifiable along some sections of track. Test pit data were not sufficient to determine whether observed variations in the character of GPR reflections relate to ballast quality.

SOMMAIRE

Les sociétés ferroviaires ont besoin d'une méthode rapide pour repérer les tronçons de voie dont l'intégrité risque de poser problème. Le principal objectif de cette étude était de déterminer l'efficacité du radar pénétrant (GPR, ground penetrating radar) en tant qu'outil pour cartographier les variations d'épaisseur et de qualité du ballast et de la sous-couche d'une voie ferrée.

Une étude par GPR a été effectuée le long de lignes ferroviaires choisies du Canadien National (CN) et du Canadien Pacifique (CP) situées au sud d'Ashcroft, en Colombie-Britannique. Trois fréquences d'antennes différentes ont été utilisées : 250, 500 et 800 MHz. Les antennes étaient montées derrière un véhicule et les données étaient colligées entre les rails. Au total, environ 26 milles de données ont été recueillies.

Une analyse des paramètres d'étude a été réalisée, afin de déterminer la fréquence d'antenne, la hauteur de l'antenne au-dessus du ballast, la vitesse d'acquisition des données et les flux de traitement les plus efficaces

C'est la fréquence d'antenne de 250 MHz qui a donné les meilleurs résultats à une profondeur d'investigation de 1 à 2 m. C'est cette fréquence qui est recommandée pour les études de reconnaissance à grande vitesse. Les antennes 500 MHz sont recommandées pour les études de détails à basse vitesse.

La hauteur de l'antenne au-dessus du ballast est critique pour un bon couplage avec le sol. Les antennes doivent être aussi près que possible du ballast, soit habituellement à environ 5 cm. De plus, il est recommandé d'utiliser une plate-forme construite exprès, montée sur un dispositif d'attelage de remorque, pour l'étude de l'assiette des rails. Cela garantirait un positionnement uniforme des antennes par rapport aux rails et au ballast.

La vitesse idéale pour l'acquisition des données est la vitesse de marche à pied. En effet, grâce à la résolution latérale augmentée qu'offre une investigation à basse vitesse, on peut s'assurer que les données sont colligées directement au-dessus du ballast, entre les traverses.

Le flux de traitement idéal comprend les étapes suivantes : superposition, filtrage passe-bande, suppression du bruit de fond, gain variant dans le temps, lissage horizontal et correction au temps zéro.

L'interface séparant le ballast et la sous-couche a pu être distinguée sur certains tronçons de voie. Les données des fosses d'essai n'étaient pas suffisantes pour déterminer si les variations observées dans la nature des réflexions du GPR étaient fonction de la qualité du ballast.

TABLE OF CONTENTS

1.0	INTRODUCTION		1
	1.1	Site Description	1
	1.2	Background	2
	1.3	Application of Ground Penetrating Radar to Ballast Mapping	2
		1.3.1. Overview of Ground Penetrating Radar	3
		1.3.2. Previous Work in Ballast Assessment using GPR	4
2.0	SURVEY PARAMETERS		5
	2.1	GPR Acquisition Parameters	5
	2.2	Survey Location Control	6
	2.3	Processing	6
3.0	RESULTS AND DISCUSSION		8
	3.1	CPR Test Survey	8
	3.2	CPR Production Survey	8
		3.2.1. CPR Line 250 MHz	8
		3.2.2. CPR Line 500 MHz	9
	3.3	CN Survey	10
	3.4	Discussion of Survey Parameters	10
		3.4.1. Antenna Frequency	10
		3.4.2. Height of Antennas above the Ballast	11
		3.4.3. Speed of Acquisition	11
		3.4.4. Data Processing	12
		3.4.5. Velocity	14
4.0	CONCLUSIONS AND RECOMMENDATIONS		15
5.0	REFERENCES		16

APPENDIX : FIGURES OF TEST DATA

1.0 INTRODUCTION

A ground-penetrating radar (GPR) survey was undertaken by Associated Mining Consultants Ltd. (AMCL) along selected CN and CPR rail lines south of Ashcroft, British Columbia. The purpose of this work was to test the effectiveness of ground-penetrating radar (GPR) as a tool to map variations in the thickness and quality of railway ballast and subgrade.

All work was undertaken in accordance with AMCL's proposal (AMP 1628) to Public Works and Government Services Canada Solicitation No. T8200-044513/A.

1.1 Site Description

The CN and CPR rail lines are located near Ashcroft, British Columbia (see Figure 1). These sites were selected by Transport Canada, in conjunction with the rail lines, because of a history of excessive maintenance on these tracks. The rail companies and Transport Canada wished to assess the viability of using GPR as a means of rapidly assessing the thickness of existing ballast, as well as assessing whether the ballast quality has been degraded. These sections of track formed a good test case.

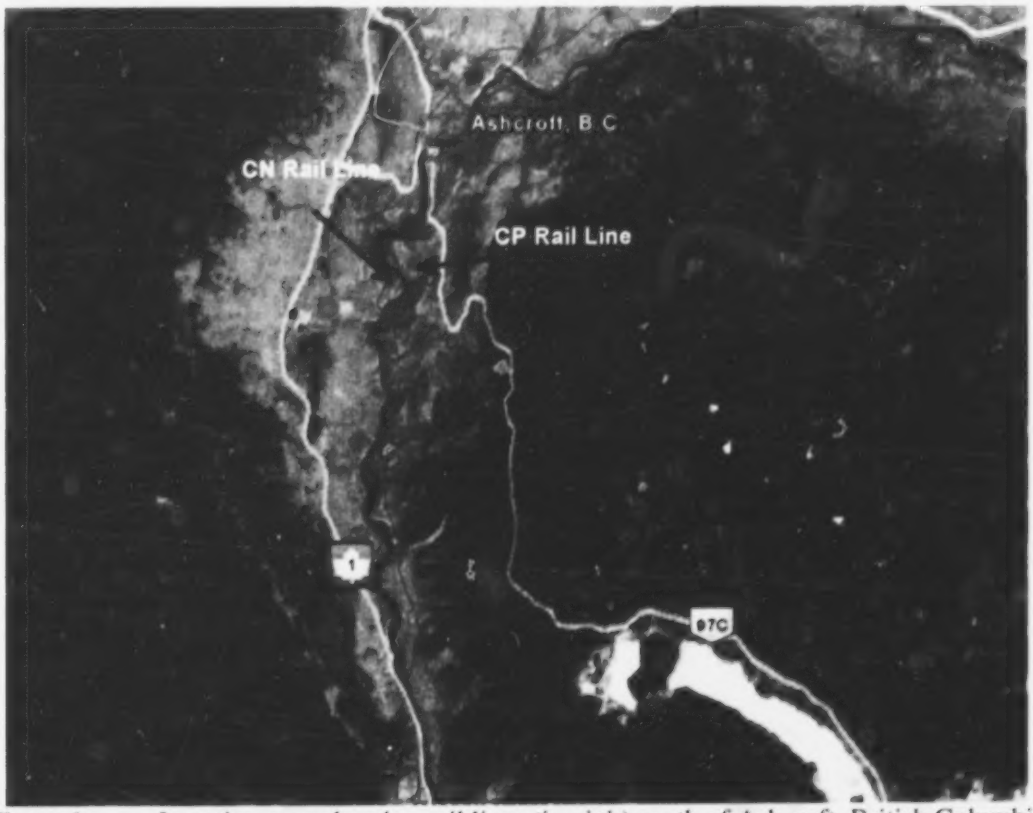


Figure 1: Location map showing rail lines (in pink) south of Ashcroft, British Columbia

1.2 Background

The main purpose of ballast beneath rail lines is to distribute the loads of passing trains and thereby protect the integrity of the tracks. To operate properly, the ballast must be clean, well drained, of uniform thickness, and must lie above a stable, uniform subgrade. Degraded ballast leads to poor track conditions, which in turn lead to low-maximum-speed zones and significant safety hazards.

In most countries, a variety of ballast or substructure factors may contribute to degradation of the track integrity, including:

- Fouling of the ballast, either by the migration of fine-grained material upwards from below, or the deposition from above by oil or engine sand. Fouled ballast leads to poor drainage conditions.
- Accumulation of water within the ballast.
- Accumulation of water within the subgrade.
- Failure or deformation of the subgrade, caused in part by excessive water content.
- Spreading and thinning of the ballast, potentially caused by inadequate shoulder ballast or plastic (high-water-content) subgrade conditions.

In Canada, additional factors that commonly cause ballast and substructure degradation relate to:

- Freeze-thaw cycles that can create significant deformation of the ballast, sub-ballast, and subgrade. These can be particularly important near tunnels, bridges, or turn-outs, wherever natural discontinuities exist within the subgrade. They will also occur at the edges of poorly drained ballast - between dry and wet ballast.
- Alterations in permafrost conditions that can lead to large-scale subgrade deformations. Permafrost alterations can be natural in origin, or can be caused by improper cold-region construction techniques.

These factors are interrelated, but generally they can be classified as resulting from either:

- Poor drainage conditions, or
- Deformation of the ballast, sub-ballast, or subgrade.

1.3 Application of Ground Penetrating Radar to Ballast Mapping

Track integrity can be better maintained if potential problem areas can be identified before they pose safety concerns, and if the underlying causes of problem areas of track can be identified. As noted above, track-integrity problems are related to poor drainage and ballast/subgrade deformation. Previous work by Olhoeft and Selig (2001), Hugenschmidt (2000), and Jack and Jackson (1998) has indicated the potential for GPR to aid in the identification of these problem areas.

The rail companies were particularly interested in detecting where the thickness of ballast was greater than 1 m. These areas generally correspond to sections of track that have repeatedly had ballast added to counteract depressions in track elevation. Since the rail companies do not have detailed records of these areas they require a tool to identify them in a rapid manner.

1.3.1. Overview of Ground Penetrating Radar

GPR is a radio-frequency electromagnetic technique that produces an image of geologic and fluid boundaries in the near-surface. A schematic of a radar system is shown in Figure 2a. The system directs a radio-frequency electromagnetic pulse towards the ground from a transmitter antenna. This pulse is partially reflected by changes in mineralogy and fluid content as well as metallic pipes or other man-made objects in the subsurface. The reflected pulses are sensed by a receiver antenna at the surface. The elapsed time between transmission and reception can be used to estimate the depth to the source of a reflection. A GPR profile, a two-dimensional image of the subsurface, is created by moving the transmitter and receiver in tandem along a line, and collecting reflected signals at regular intervals. When these reflected signals are plotted side-by-side in a distance-versus-time plot, a cross-section of the subsurface geologic structure is created.

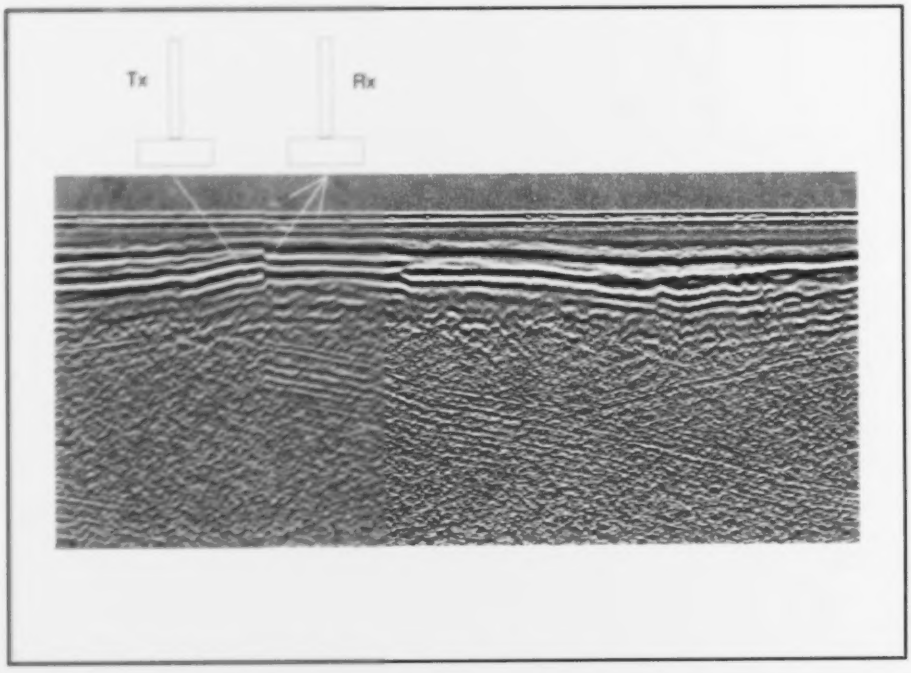


Figure 2a: Schematic of GPR acquisition, with example data. The radar transmitter (Tx) emits a radio-frequency pulse into the subsurface. The pulse reflects off layering in the subsurface, and returns to the surface where it is detected by the receiver (Rx). These data show the bottom of a shallow river, as imaged from the ice above.

Radar waves reflect off any boundary that represents a change in dielectric constant, which is a measure of how easily molecules can oscillate in an alternating electric field. Radar waves are heavily attenuated by electrically conductive material, whereas they can pass relatively unattenuated through electrically resistive material. Therefore good GPR images can be expected in clean dry silica sands that contain large dielectric contrasts. In material with little or no dielectric contrasts, or in electrically conductive materials such as seawater, clay, or certain lake sediments, GPR is unlikely to be an effective imaging tool.

1.3.2. Previous Work in Ballast Assessment using GPR

Previous work by Olhoeft and Selig (2001), Hugenschmidt (2000), Jack and Jackson (1998), and Yelf (2005), has shown that GPR is capable of mapping both the ballast and sub-ballast thicknesses, as well as the topography of the subgrade. Through reflection-amplitude analysis, one may be able to infer areas of ballast fouled by fine-grained material such as clay. It is also sometimes possible to infer areas of ballast fouled by waste rail material through analyzing the textural character of the recorded GPR signals. By placing antennae both between and outside the rails, both in-line and cross-line sections of ballast structure can be obtained.

There are certain challenges associated with using GPR in railway environments - the interference caused by railway ties, the metal tracks and nearby installations integral to railway operation. The acquisition parameters and subsequent data processing must anticipate these challenges and aim to mitigate them.

Despite these challenges GPR is now an established technique for analyzing railway ballast in Australia and Europe. However, very little has been done in Canada to assess the viability of using this technique.

Our two technical advisors, Dr. R. Yelf and Mr. P. Jackson, both have extensive experience with GPR acquisition on railway ballast. Dr. Yelf has extensive experience mapping ballast thickness in Australia. Mr. Jackson of IMC, based in Huthwaite, UK, has done work in mapping not only thickness but also ballast cleanliness. In addition, IMC has developed ballast material to lay at the base of the ballast. This material contains metal fibres to improve the ability to map ballast thickness accurately. In this way IMC can conduct GPR surveys year by year and repeatedly map ballast thickness and ballast cleanliness by analysing reflection amplitude.

2.0 SURVEY PARAMETERS

For the CN and CPR surveys a framework was constructed and mounted on a vehicle as shown in the schematic in Figure 2b. The radar antennas were hung from this framework between the rails behind the vehicle. If needed, other antenna pairs could be mounted at either side of the vehicle from side extensions of the framework.

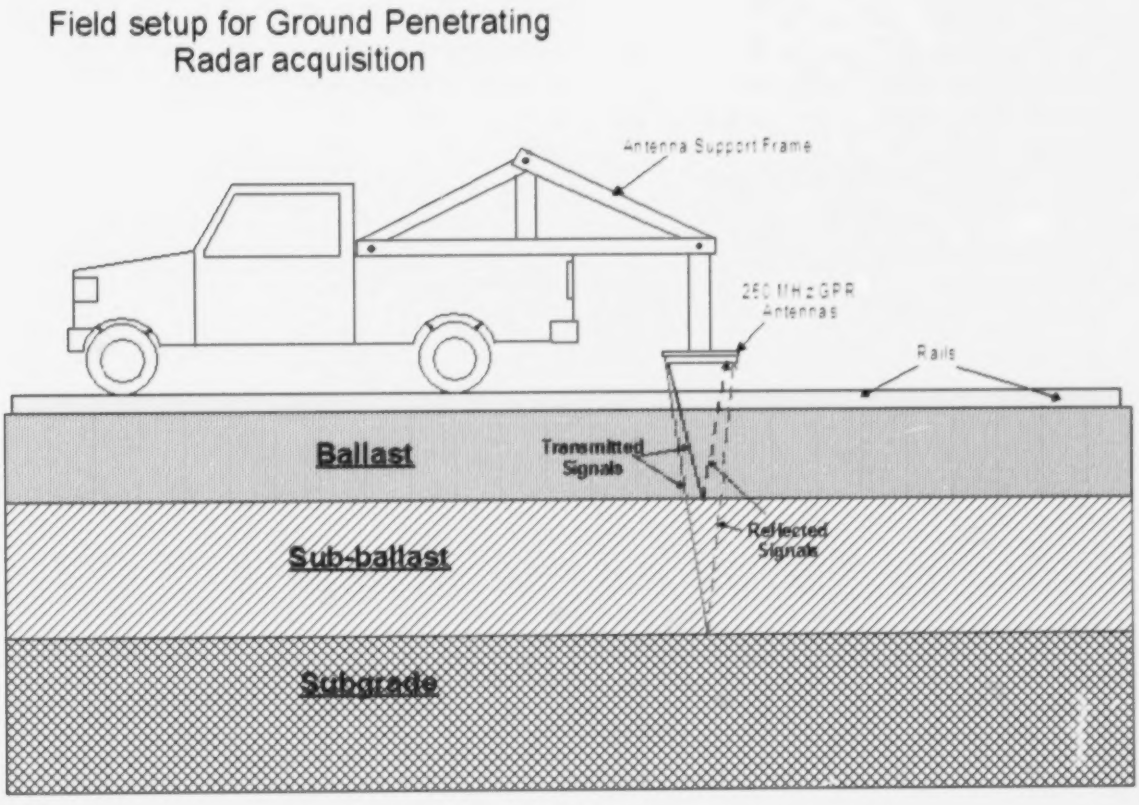


Figure 2b: Schematic of field setup for GPR acquisition

2.1 GPR Acquisition Parameters

Prior to conducting the field work, AMCL held extensive discussions with two technical advisors, R. Yelf and P. Jackson. Both advisors had two major recommendations. First, they recommended that ground-coupled antennas should be used instead of air-launched antennas, since the air-launched versions used very high frequencies (1 GHz or higher) and did not hold much promise of obtaining the required penetration depths. AMCL therefore used a system manufactured by Mala Geoscience that uses ground-coupled antennas. The frequencies chosen were 250-MHz, 500-MHz, and 800-MHz. The 250-MHz antennas were chosen as having the best penetration depth in a package that would fit between the rails. The 500 MHz and 800 MHz were chosen to test higher-resolution approaches.

The second major recommendation was that to be effective, data should be collected at a very close trace spacing (on the order of 2-to-5 cm). In their experiences, this meant that data needed

to be acquired at a walking pace. It was not possible to meet this requirement, since the available track time and the amount of track to be covered precluded slow-speed acquisition for much of the survey.

The acquisition parameters used for each antenna are as follows:

250 MHz:

Distance triggered	0.3 m
Sample rate	4969 MHz
Number of samples	151
Number of stacks per trace	1

500 MHz

Time triggered	.01 s
Sample rate	2460 MHz
Number of samples	192
Number of stacks per trace	1

800 MHz

Distance triggered	0.3 m
Sample rate	1136 MHz
Number of samples	322
Number of stacks per trace	1

2.2 Survey Location Control

A Trimble WAAS-Enabled GeoXT GPS system was used for real-time location information. The GPS data were merged with the GPR data in real-time, ensuring that GPR traces were stamped with GPS locations and, more importantly, GPS times, as they were acquired. As a back-up, GPS data were also stored independently in the Trimble unit.

The GPR traces were also located using a distance-measurement and triggering system. This system uses optical encoders that record distance traveled by a calibrated wheel. The encoders were also used to trigger the radar acquisition units, to ensure equal trace spacing throughout the survey. These systems are typically accurate to 1 m in 5000; the accuracy is then further improved by calibrating the readings against known positions ("rubber sheeting"). Redundant cross-checks were made on the calculated positions, by placing markers in the recorded GPR and GPS data files. These markers were inserted into the files when the equipment passed known surface reference points such as mileage reference markers.

2.3 Processing

The processing steps used are designed to convert the raw radar data into cross-sections that can be interpreted in terms of subsurface discontinuities. These are standard geophysical processing techniques, and will not be described in detail here. The reader is referred to Yilmaz (1987) for technical data-processing descriptions. An in-depth discussion of the processing steps, and their effect on the data can be found in section 3.4.4.

The data were processed using the following steps:

1. Data converted from proprietary Ramac format to SEGY format (Society of Exploration Geophysicists - Y format), a geophysical-industry standard for time-series data.
2. Distances along the railway were assigned to trace-header word **offset**.
3. Data were stacked and band-pass filtered to remove low-frequency wow and high-frequency noise.
4. Background noise removed with an x-direction mean-trace subtraction filter.
5. Data gained using time-varying gain function and smoothed.
6. Potential subsurface discontinuities were identified, and associated reflection times assigned to SEGY header words d1, d2, f1, and f2.
7. Time-to-depth conversions performed using a velocity of 1.2×10^8 m/s.
8. Sample cross-sections plotted as gray-scale depth images.

Data files provided are in both raw (unprocessed) and processed format. This allows the data to be reprocessed at any time, without concern for whether any processing-created artifacts exist in the data files.

3.0 RESULTS AND DISCUSSION

The CPR and CN tracks were surveyed a few months apart, since it was extremely difficult to coordinate track time and vehicle availability for both rail companies at the same time. As a result the two surveys used slightly different equipment.

3.1 CPR Test Survey

A survey of the CPR track south of Ashcroft between Mile 48.5 to Mile 51 was carried out on August 17 and 18, 2005. The first day of the survey was spent testing acquisition parameters. As indicated above, the survey design was influenced by communications with Dr. Richard Yelf and Mr. Peter Jackson. Each of these individuals has significant experience with collecting and processing GPR data on railway beds. Their primary recommendations included acquiring the data at walking speed. This was not possible in this case because of the restricted time window available for surveying on the track.

For this survey the Mala Geoscience Ramac II multi-channel GPR system was used with three antenna pairs: 250-MHz, 500-MHz and 800-MHz. The 250-MHz and 800-MHz were mounted behind the vehicle at a height of approximately 30 cm above the rail bed. Due to space restrictions, the 500-MHz antenna pair was slung to the side also at a height of approximately 30 cm above the ballast. The antenna were oriented parallel to the tracks.

An example of the test data from each antenna pair is shown in Figure 3. As expected, the penetration depth with the 800-MHz antennas (Figure 3a) was very shallow - on the order of 50 cm. In these data the interpreted ballast layer can be identified in the first 200 traces at a depth of 0.5 m. It cannot be clearly followed throughout the section, nor can any other features be identified below 0.5 m. Although the 800-MHz antennas provided good quality data, the penetration depth was not deep enough to image the target depths. Therefore these antennas were not used in subsequent surveys.

The 500-MHz data (Figure 3b) are generally of poorer quality. It is felt that the poor quality is mainly caused by the height of the antennas above the ballast surface. The 250-MHz data (Figure 3c) show penetration sufficient to image the base of the ballast, and potentially the sub-ballast - 1-2 m.

3.2 CPR Production Survey

On August 18, a length of CPR track south of Ashcroft was surveyed - from mile 48.6 to mile 54.7. The results from the test survey indicated that, as expected, the 250-MHz antennas provided the best results in the target depths. The 500-MHz antennas were placed to the side of the vehicle to image lateral variations in ballast depths on either side of the tracks. The 500-MHz antennas are smaller and more appropriately placed to the side rather than between the tracks.

3.2.1. CPR Line 250-MHz

The 250-MHz data for the CPR track are shown in Figures 4 to 27. For each section of track two images are shown. The upper image is that of the radar data with the interpretation of the GPR

reflections overlain. The lower image is the interpretation alone. The sections are shown with chainage in miles along the x-axis and depth along the y-axis.

The 250-MHz data show in most areas a continuous reflector at a depth of approximately 0.5 -1.0 m. This reflector has been interpreted as the base of the ballast, and is identified by a red line on the radar data. Quality varies throughout the survey and in some instances, such as mile 52.84 -53.02 in Figure 23, it is very difficult to define this horizon. This difficulty is likely related to the interference between the reflection from the rail ties with the subsurface reflection.

In some cases, particularly Mile 54.7 to Mile 55.04 in Figure 4, a very strong horizontal reflector appears at the top of the section. It is believed that this reflector is from the metal rails themselves. It can obscure the reflection from the base of ballast making it difficult to identify. A clear example of this can be seen at Mile 54.95 in Figure 4 where the ballast shallows enough to be obscured by the rail reflection. At Mile 54.96 the ballast dips slightly and the reflection emerges from beneath the rail reflection.

One would expect the rails to be a constant distance from the antennas and therefore to result in a reflection at a constant time in the section. It should, therefore, be simple to remove the reflection by subtracting the average trace from the section. In the case where the rail reflection is not removed, it is assumed that the antennas have moved slightly with respect to the rails. As the antennas were not rigidly attached to the vehicle, such movement could have occurred.

The sub-ballast has been identified in most areas and has been marked in blue. Other identifiable reflections below these two main ones have been identified in green. These reflections may be from general fill or from the native material beneath the fill.

Test pit data provided by BGC Engineering Ltd. have been overlain where available. The main reflection identified in the radar survey correlates reasonably well with the base of the ballast. In some cases, it correlates with the region defined as the lower ballast layer, suggesting that there is not always a clear contrast in electrical properties at the ballast/sub-ballast boundary. It does, however, appear to be located within. The lower reflections identified in the data appear to occur in the region of the base of the sub-ballast layer. At times, however, this reflection is more coincident with the base of the general fill.

There are several possible reasons for this lack of exact correlation. The location of the test pit may be several metres from the actual radar location. In addition the antennas could be swaying from side to side with the motion of the vehicle. This would cause variations in the apparent depth to and strength of a reflection.

There are noticeable differences in the character of the radar reflections along the length of the track surveyed. For example, the reflections in Figure 16 between Mile 49.02 and Mile 49.10 show a reasonably quiet zone above, while the reflections in Figure 16 between Mile 49.10 and Mile 49.16 show a speckled, noisy region above. It is possible that the speckled region relates to relatively dirty ballast, whereas the quiet zone relates to clean ballast. However, sufficient test-pit data were not available to confirm this.

3.2.2. CPR Line 500-MHz

The 500-MHz data for the CPR track are shown in Figures 28 to 55. For each section of track two images are shown. The upper image is that of the radar data with the interpretation overlain.

The lower image is the interpretation alone. The sections are shown with chainage in miles along the x-axis and depth along the y-axis.

In general these data were quite poor. A reflection has been identified in these data, but little confidence is placed in it. However, in all cases this horizon was identified at between approximately 0.5 m and 1.0 m. As with the 250-MHz data, this lies within the region of the lower ballast and upper sub-ballast.

It is felt that the poor quality of the data may be due to the height of the antennas above the ballast (nominally set at 30 cm). However, as the ballast to the side of the track had severe topographic variations, this separation could range between 10 and 50 cm. In a few locations, most markedly in line CPR52, some indication of the existence of lower reflections can be identified (see in particular Figure 53). These may be the base of the sub-ballast.

3.3 CN Survey

After analysing the results of the CPR survey, the CN survey was designed. Equipment availability restricted the survey to a single channel system - Mala Geoscience Ramac II. Data were collected on the CN track on November 17, 2005. In the CN survey, only the 250-MHz antennas were used as very little significant information was obtained using the 500-MHz antennas. The height of the antennas above the rail bed was significantly reduced in order to improve coupling of the antennas with the ground. In order to protect the antennas from rocks and other debris lying on the track, the antennas were placed in a box of high density plastic.

An additional modification in the survey was a change in the orientation of the antennas. In the earlier CPR survey, the antennas were oriented parallel to the tracks since this presented the most lateral clearance between the antennas and the rails. Therefore, the radiation pattern emitted from the antennas included the metal rails and could have been the cause of some of the poorer signals. By rotating the antennas perpendicular to the rails, more of the radiated energy would miss the rails thereby producing a cleaner signal.

Unfortunately there were no ground-truthing data available at the CN track for comparison with the GPR results. As with all geophysical methods, other direct information such as test pits and drill data are invaluable to correct interpretation of the results.

The CN data were therefore interpreted using the results of test pit information on the CPR line as a general guide to expected structure and depths. An interpreted depth to the base of the ballast is marked on the data in Figures 56 to 72 in red. Lower reflections which may be the base of the sub-ballast are marked in blue. Occasionally a deeper reflection occurs - for example in Figure 65 - possibly marking the native material underneath the fill. These reflections are indicated in green.

3.4 Discussion of Survey Parameters

3.4.1. Antenna Frequency

The frequency of the antennas used to collect the data will affect the results. In general, a higher frequency antenna will produce greater vertical resolution at the expense of poorer penetration depths. The choice of antenna will, therefore, reflect the intended target of the survey. In the work done by Dr. R. Yelf, 200-MHz and 400-MHz antennas are used. On the CPR line three

antenna frequencies were used: 250-MHz, 500-MHZ and 800-MHZ. Figure 73 shows data from the same section of line collected with these three antennas. The 250-MHz and 500-MHz antennas were chosen as they are in the same range as those used by Yelf and provide the best chance to obtain the required depth penetration while still allowing reasonable resolution. The 800-MHz antennas were chosen to test whether they could provide both a higher resolution and the ability to collect the data more rapidly.

The 500-MHz data show very poor results. In part this could be due to the high frequency being unable to penetrate to a useful depth. However, due to space restrictions on the vehicle these antennas were mounted to the side of the rails, above ballast that sloped steeply away from the track. This is discussed in more depth in section 3.4.2.

The 800-MHz and 250-MHz data show much better results. Depth of penetration for the 250-MHz antenna is greater than that of the 800-MHz, which rarely penetrates below 50 cm.

3.4.2. Height of Antennas above the Ballast

In order for the maximum amount of energy to be directed into the ground, the antennas must be coupled as well as possible to the surface, ideally touching the surface of the ground. In a survey over a rail bed this is obviously not possible due to the risk of catching the antennas on a railway tie or other obstacles such as rocks between the rails.

In the CPR survey, caution prevailed and the 250-MHz and 800-MHz antennas were set at a height of about 30 cm above the ballast. Due to space and logistical considerations, the 500-MHz were mounted to the side of the acquisition vehicle, and resulted in separation of 10 to 50 cm between antenna and ballast. The height variation is caused by topographic variations in the sloped sides of the ballast. This resulted in very poor results as shown in the top image in Figure 74.

In the CN survey, the 250-MHz antennas were mounted at a height of two centimeters above the ties. To protect the antennas they were placed in a box of high density plastic. The improvement in results is quite clear as shown by comparison with the CN results shown in the lower image of Figure 74.

3.4.3. Speed of Acquisition

The speed at which the vehicle travels along the rails will of course affect the resolution of data available. In Dr. Yelf's work he acquires data at a walking speed. On the CN and CPR tracks, such low speeds were not possible for the production survey as the available time window for using the track was quite short. However, in order to test the effect of acquisition speed, short lines were collected between 5 and 50 km/h. Each antenna and data acquisition system is capable of different rates of acquisition, so the number of traces per second will vary. However, to show the effect of vehicle speed on survey results, a section of survey is shown in Figure 75a. This corresponds to an acquisition rate of 12.43 traces per metre. Figure 75b shows the same section with the traces decimated to mimic the results expected from a vehicle traveling approximately four times the speed. The result is an acquisition rate of 4.14 traces per metre.

Clearly the slower the speed of the vehicle, the greater the resolution. At a given speed the acquisition rate must be fast enough that traces are not only acquired over rail ties but also between them. Therefore if a detailed interpretation of the ballast is needed, a slow (5-10 km/h)

vehicle speed is desirable. However, if the objective of the survey is to identify larger trends and structure in the ballast layer, a faster speed is preferable. This is not only due to the obvious increase in survey efficiency, but also to the observation that small-scale, less important details are diminished in faster surveys, leaving the targeted, large-scale structure more easy to interpret.

3.4.4. Data Processing

The processing steps applied to GPR data can greatly enhance the ability to successfully interpret the data. There is often a trade-off, however, between superior processing and efficiency. Several processing techniques are very computer intensive. This can be an issue if, as in the case of this survey, many kilometres of data need to be processed. J. Hugenschmidt recommends the following processing steps:

1. Bandpass filtering
2. Correction of surface reflection to time zero
3. Migration
4. Horizontal scaling
5. Stack, eight-fold
6. Background removal
7. Horizontal smoothing
8. Vertical gain correction

We used Hugenschmidt's processing stream as a starting point and modified it somewhat after extensive experimentation with these processing steps and several others not considered by Hugenschmidt.

The effects of several different processing methods were investigated in this study. These are standard geophysical processing techniques. A brief description of each processing step is given below but will not be described in full detail here. The reader is referred to Yilmaz (1987) for technical data-processing descriptions. Figure 76 displays a data set at each stage of the processing stream, showing alternate processing when applicable. The raw data are shown in Figure 76a.

Energy Balance:
This step was not used in Hugenschmidt's processing stream, but it was felt that examining it would be useful. Sometimes the amount of energy going into the ground varies due to a change in coupling of the antenna with the ground. By balancing the energy from trace to trace these variations can be eliminated. A negative aspect of this is that some of the energy variations in the signal are due to actual variations in the reflectors. For example, a change in water content will change the strength of the reflected signal. To counter this possible effect, the energy can be balanced according to the energy found only within a limited window, in this case the air and ground arrival. The balanced data are shown in Figure 76b. The amplitudes during this step in the processing stream are balanced to 1, hence the apparent reduction in amplitudes.

Time Zero Correction:
In radar data there is some "dead" time in each trace that occurs before the real signal arrives. In order to accurately determine the depth plot of the reflected arrivals, the true "time zero" must be determined. In AMCL's proprietary software used to process these data, the time zero correction is considered in processing by determining the sample number at which the first arrival occurs. This is determined through close examination of several traces throughout each unprocessed

survey line. The entire trace remains intact throughout the processing stream. Only in the final, plotting phase are data before the time zero removed.

Migration:
The transmitted energy from the radar antenna is not a focused beam, but rather a roughly conical shape. As such it "sees" sideways as it propagates through the subsurface. A point source such as a large rock or railway tie will, therefore, produce a characteristic hyperbola in the data, with the apex of the hyperbola indicating the location of the boulder. The hyperbola can interfere with other reflections making interpretation difficult. Migration is a process in which the energy in these diffractions is "collapsed" to the apex, thereby "cleaning up" the data and making interpretation easier. Migration can be a computer intensive process.

Horizontal Scaling:
This step is simply assigning correct locations to each trace and is described above in section 2.2.

Stack:
Stacking sums several traces in order to improve signal to noise ratio. In this survey stacking was 10-fold.

Band Pass Filter:
Depending on the electrical properties of the ground, the transmitted signal may induce a slowly decaying low-frequency "wow" on the radar trace, which is superimposed on the higher frequency reflections. The removal of this effect is accomplished by applying an appropriate band-pass filter to the data. Post-filtered data are shown in Figure 76c.

Removing Average Trace (background removal):
In radar data there is always energy which travels directly from the transmitting to receiving antenna, both through the air and through the ground. This results in a constant flat signal at early times. The air and ground arrival mask any reflected signal from shallow horizons. This can be clearly seen as the horizontal lines in the upper sections of Figures 76a-c. By subtracting average trace this air and ground arrival can be removed, revealing reflected signals as seen in Figure 76d. A negative effect of removing the average trace occurs when the target boundary is flat lying. In this case the signal of interest will also be removed. This can be a considerable issue in ballast identification as often the ballast is horizontal.

In order to aid interpretation, many lines were processed twice, once with removing an average trace calculated from the entire line, and then again with a moving window of average trace subtraction. This window width was often varied multiple times to assess the continuity of the signal.

Gain:
The reflected signal strength decreases rapidly in time. Therefore, a gain is used to amplify lower signals at later times. Two gains were compared for these data: a time varying gain and an AGC (automatic gain control). The time varying gain allows for differences in signal strength to be retained in the processed data. This could be important for interpreting areas of varying water content. Such areas have a high dielectric contrast and, therefore, one would expect variations in the strength of reflections. The AGC gain will amplify every reflector scaled to maximum reflection in a specified time window. This means that variations in the amplitude of reflection are lost. On the other hand, AGC gain will improve the ability to interpret deeper reflections

which may not be clear with a time varying gain. The data amplified with a time varying gain are shown in Figure 76e, while those with an AGC gain are shown in Figure 76f.

Horizontal Smoothing:
A horizontal smoothing is applied as the last step to diminish jitter in the signal. Figures 76g and 76h show the data after horizontal smoothing for linear and AGC gained data respectively. In this survey it was decided not to use an energy balance on the data. Although all data were processed with and without balance applied, ultimately it was felt that a more accurate representation of variations in signal strength would be more beneficial for interpretation. For the same reason a time varying gain was used instead of an AGC gain. In some instances, where overall signal strength was low, the data were processed in both ways and compared in order to obtain a final interpretation.

Migration was not used in processing these data. The hyberbolae from the railway ties were not very noticeable and it was not felt that migration was warranted. In addition, as acquisition speeds were not able to be as slow as recommended, the necessary resolution to define the hyberbolae was not achieved.

To summarize, the final processing included:

1. Horizontal scaling (assignment of location)
2. Stacking
3. Band pass filtering
4. Remove average trace (background removal)
5. Time gain
6. Horizontal smoothing
7. Correction to time zero

Data files provided to Transport Canada are in both raw (unprocessed) and processed format. This allows the data to be reprocessed at any time, without concern for whether any processing-created artifacts exist in the data files.

3.4.5. Velocity

As explained above in the overview of ground-penetrating radar, a radar survey records the reflected signal strength as a function of time. In order to convert the arrival times of reflections to depths, the velocity at which the waves are travelling must be known. The velocity of electromagnetic waves varies with the medium through which they are travelling. Generally, a velocity is obtained from measuring the time to a reflector of known depth at one location and applying this velocity to the survey. At the CN site no ground truthing was available.

An alternative is to analyze hyperbolic refractions from point sources such as boulders beneath the surface. This was the method used in this survey. Twelve hyberbolic reflections were analyzed, resulting in an average velocity of 0.12 m/ns. This velocity was used to convert times to depths throughout the survey.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The experience gained from the CPR survey was very useful for improving parameters in the CN survey. The data from the CN tracks show significant improvement over those from the CPR tracks.

Several boundaries could be identified in both surveys. These have been interpreted as identifying the base of the ballast and sub-ballast. In the CPR survey, where test pit data were available, the upper reflection generally correlated with the base of the ballast. In some cases, it correlated with the lower portion of the ballast. In these cases, it is possible that the base of the ballast beside the track, where the pit was excavated, is higher than the base of the ballast between the tracks. The lower reflection generally corresponded with the base of the sub-ballast, but at times correlated with a zone within the native material. The variations in the correlations most likely relate to varying native material type. No test pits were available to aid in the interpretation of reflections in the CN survey.

The 250-MHz antennas provided the best results for the target depth of 1 to 2 m. While the 800-MHz antennas provided good results, the penetration depth was too shallow to be of use in this type of survey. It is therefore recommended that only the 250-MHz antennas be used in high-speed reconnaissance surveys, to image between the rails. The 500-MHz antennae, although not well suited to collecting high-speed data to the sides of the tracks, may prove effective during low-speed detailed surveys. In these situations, the antennae can be carefully adjusted to the local side-ballast topography, to improve ground coupling.

Clear variations in GPR character were observed. These variations may relate to the relative cleanliness of the ballast. However, test-pit data were not sufficient to confirm this.

It is highly recommended that future surveys be collected at walking speed where possible. The higher resolution provided by a slower survey will ensure data are collected directly over the ballast in between the rail ties. One possible option would be to collect data at a higher speed over the entire track to identify potential problem areas. These areas could then be re-surveyed at a slower speed to provide the required detail for an assessment of the status of the ballast and sub-ballast.

In addition, it is clear that the antennas should be placed as close to the rail bed as possible to improve antenna coupling. Attention should be paid to the orientation of the antennas. If possible they should be oriented perpendicular to the rails in order to reduce the effect of the rails on the data.

The mounting of the radar antennas to the survey vehicle can be critical to collecting good quality data. It is recommended that a purpose-built, trailer hitch mounted platform be constructed for use in railbed surveys. This would ensure consistent location of the antennas with respect to the rails and ballast.

5.0 REFERENCES

Hugenschmidt, J., 2000, Journal of Applied Geophysics 43 (2000), p.147-155.

Jack, R., and Jackson, P., 1998, Imaging attributes of railway track formation using GPR: Proceedings of the 1st International Railway Conference, London, U. K.

Jackson, P., 2005, Personal Communication.

Olhoeft, G., and Selig, E., 2002, Ground penetrating radar evaluation of railway track substructure conditions: 9th International Conference on Ground Penetrating Radar, Santa Barbara, CA, Koppenjan and Lee, eds., Proc. of SPIE vol. 4758, p. 48-53.

Yelf, R., 2005, Personal Communication.

Yilmaz, O., 1987, Seismic Data Processing: Society of Exploration Geophysicists.

APPENDIX

Figures of Test Data

Ballast Investigation
Ground-Penetrating Radar
CN/CPR Rail Line, Ashcroft, B.C.

FIG. 3: CPR Test Survey
Examples from 250, 500 and 800 MHz Antennas

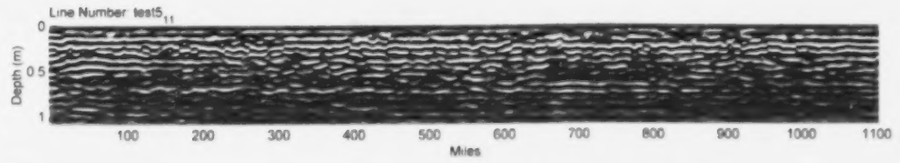


Figure 3a: 800 MHz Antennas

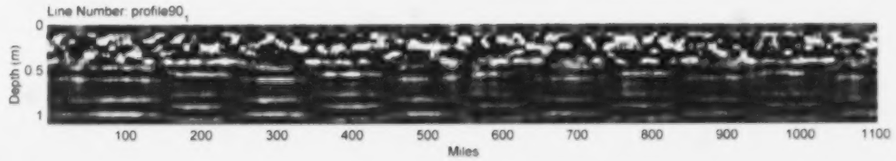


Figure 3b: 500 MHz Antennas

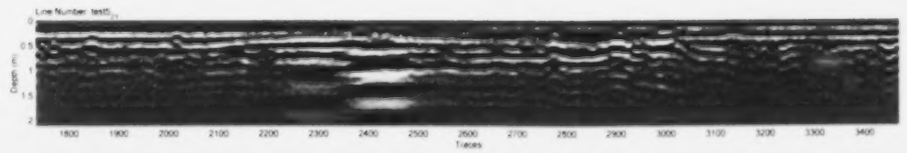
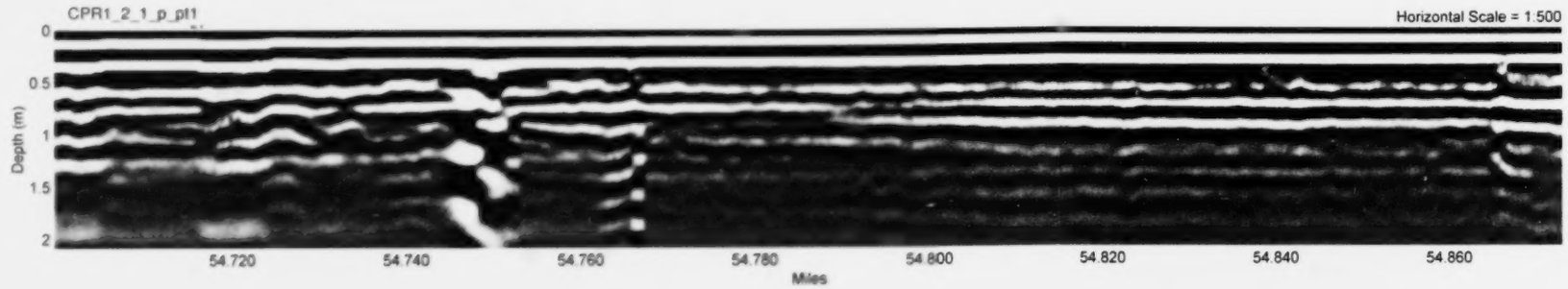


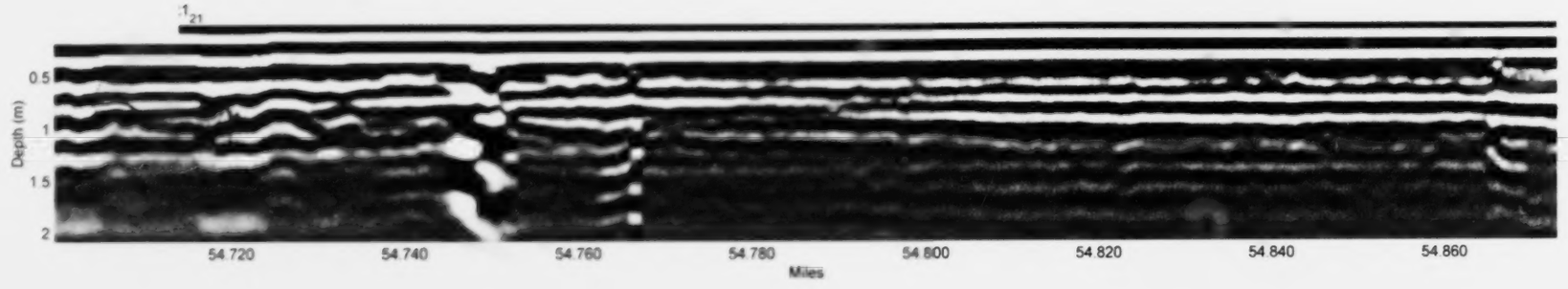
Figure 3c: 250 MHz Antennas

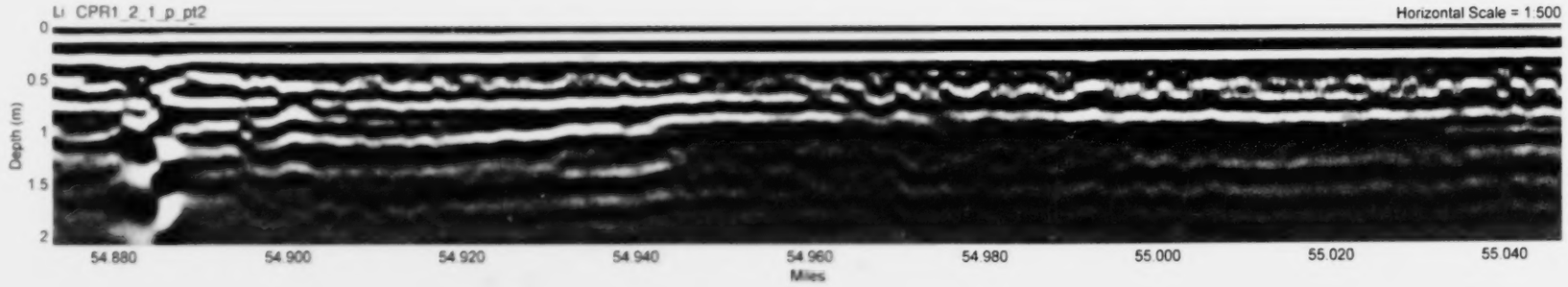
IMC
Associated Mining Consultants Ltd.

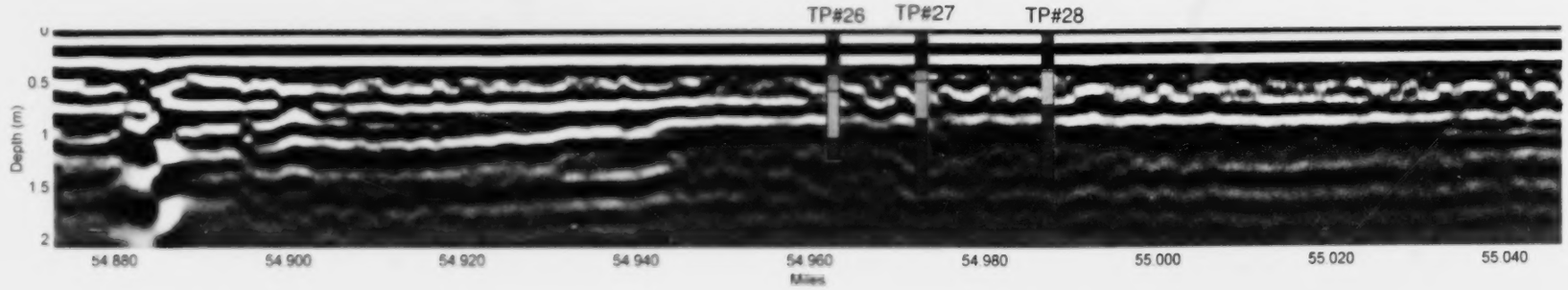
Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 4: CPR1_2a: 250 MHz GPR Data
Mile 54.7 to Mile 55.04

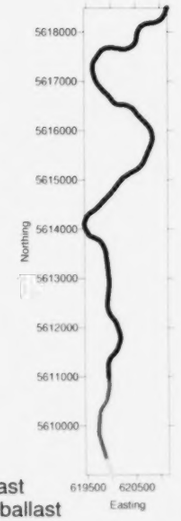








LOCATION OF SURVEY



Section of track imaged (approx.)

CPR Line #1

Total CPR line in survey

GPS coordinates NAD83 Zone 10

RADAR LEGEND

linterpreted base of ballast

Interpreted base of sub-ballast

TEST PIT LEGEND

BALLAST. LIGHT TO MEDIUM-GREY, COARSE ANGULAR GRAVEL. APPROX. NOM. DIAM. = 2.4cm

BALLAST. ANGULAR TO SUB-ANGULAR GRAVEL. MEDIUM TO DARK-GREY, LOCALLY OXIDIZED TO ORANGE-BROWN COLOUR. TRACE LOOSELY-PACKED MATRIX OF SOOTY TO OILY SILTY-FINE SAND MIXED WITH A VARIETY OF RAIL BED DETRITUS, ORGANICS AND WOOD SPLINTERS. APPROX. NOM. DIAM. = 2.2cm

SUB-BALLAST. SUB-ANGULAR TO SUB-ROUNDED GRAVEL AND SAND. DARK GREYISH-BROWN MIXTURE OF FINE TO COARSE GRAVEL, WITH A LOOSELY-PACKED SANDY MATRIX. LOCALLY CONTAINS A COMPONENT OF GRITTY COAL AND CRUSHED, FINE SLATEY-SHALE. GRAVEL PARTICLES LOCALLY OXIDIZED TO A YELLOWY-ORANGE/BROWN COLOUR. APPROX. NOM. DIAM. = 1.2cm

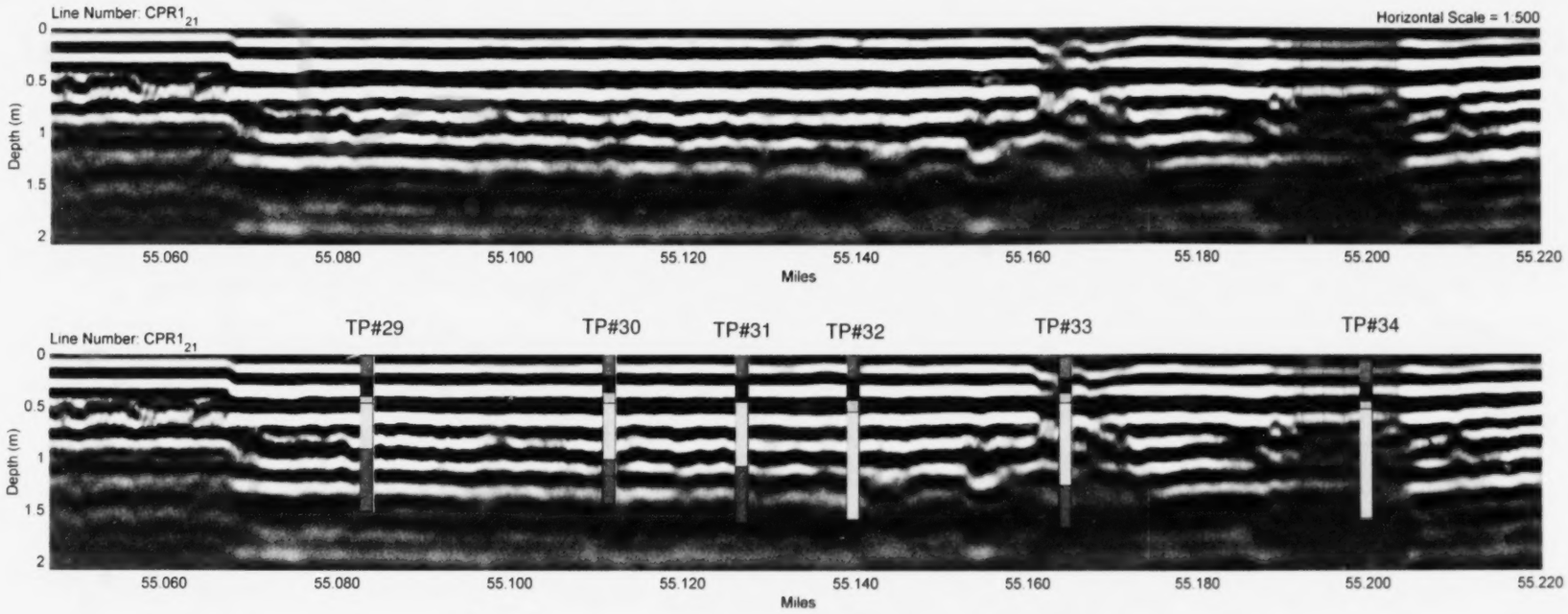
SUB-BALLAST. SUB-ROUNDED TO ROUNDED FINE GRAVEL AND SAND. LIGHT MUDDY-GREY AND SILTY-CLAY COATING. TRACE COARSE GRAVEL MIXED WITH FINE GRAVEL LOCALLY. LOOSE GRITTY MATRIX OF 10-20% SILTY-SAND. APPROX. NOM. DIAM. = 1.2cm

GENERAL FILL. POORLY-GRADED SANDS, SILTY TO CLAYEY-SAND AND GRAVEL MIXTURES, CRUSHED SLATEY-SHALE HORIZONS, AND MIXTURES OF COARSE SAND, COAL AND RAILWAY-CINDER/DEBRIS. VARIABLE THICKNESSES AND DISTRIBUTION OF BEDS. LOCAL OXIDIZED SAND.

LOCAL NATIVE MATERIAL. LIGHT-GREY TO TAN SILTY-CLAY AND SILT WITH TRACE CLAY AND FINE SAND. SILTY-CLAY COMMONLY RHYTHMICALLY LAMINATED OR INTER-BEDDED WITH COARSE, ROUNDED SAND AND FINE GRAVEL HORIZONS.

(Test pit data and legend from BGC Engineering report 0087-C32-09)

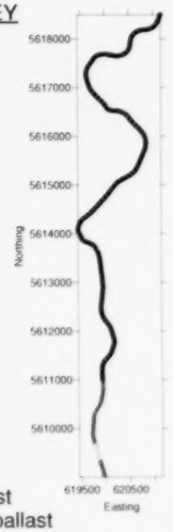
IMC
Associated Mining Consultants Ltd.



Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 5: CPR1_2b: 250 MHz GPR Data
Mile 55.04 to Mile 55.22

LOCATION OF SURVEY



Section of track imaged (approx.)

CPR Line #1

Total CPR line in survey

GPS coordinates NAD83 Zone 10

RADAR LEGEND

Interpreted base of ballast

Interpreted base of sub-ballast

TEST PIT LEGEND

BALLAST. LIGHT TO MEDIUM-GREY, COARSE ANGULAR GRAVEL. APPROX. NOM. DIAM. = 2.4cm

BALLAST. ANGULAR TO SUB-ANGULAR GRAVEL. MEDIUM TO DARK-GREY, LOCALLY OXIDIZED TO ORANGE-BROWN COLOUR. TRACE LOOSELY-PACKED MATRIX OF SOOTY TO OILY SILTY-FINE SAND MIXED WITH A VARIETY OF RAIL BED DETRITUS, ORGANICS AND WOOD SPLINTERS. APPROX. NOM. DIAM. = 2.2cm

SUB-BALLAST. SUB-ANGULAR TO SUB-ROUNDED GRAVEL AND SAND. DARK GREYISH-BROWN MIXTURE OF FINE TO COARSE GRAVEL, WITH A LOOSELY-PACKED SANDY MATRIX. LOCALLY CONTAINS A COMPONENT OF GRITTY COAL AND CRUSHED, FINE SLATEY-SHALE GRAVEL PARTICLES LOCALLY OXIDIZED TO A YELLOWY-ORANGE/BROWN COLOUR. APPROX. NOM. DIAM. = 1.2cm

SUB-BALLAST. SUB-ROUNDED TO ROUNDED FINE GRAVEL AND SAND. LIGHT MUDDY-GREY AND SILTY-CLAY COATING. TRACE COARSE GRAVEL MIXED WITH FINE GRAVEL. LOCALLY, LOOSE GRITTY MATRIX OF 10-20% SILTY-SAND. APPROX. NOM. DIAM. = 1.2cm

GENERAL FILL. POORLY-GRADED SANDS, SILTY TO CLAYEY-SAND AND GRAVEL MIXTURES, CRUSHED SLATEY-SHALE HORIZONS, AND MIXTURES OF COARSE SAND, COAL AND RAILWAY-CINDER/DEBRIS. VARIABLE THICKNESSES AND DISTRIBUTION OF BEDS. LOCAL OXIDIZED SAND.

LOCAL NATIVE MATERIAL. LIGHT-GREY TO TAN SILTY-CLAY AND SILT WITH TRACE CLAY AND FINE SAND. SILTY-CLAY COMMONLY RHYTHMICALLY LAMINATED OR INTER-BEDDED WITH COARSE, ROUNDED SAND AND FINE GRAVEL HORIZONS.

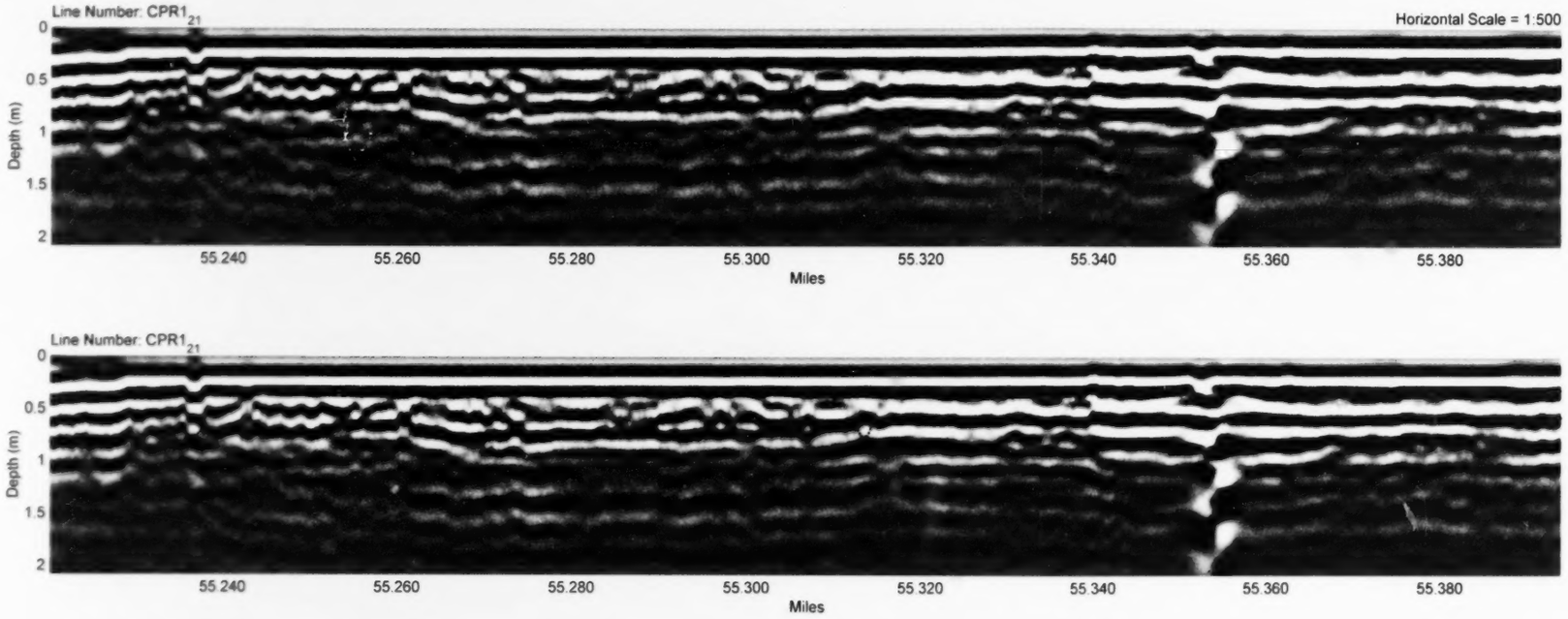
(Test pit data and legend from BGC Engineering report 0087-032-09)

IMC

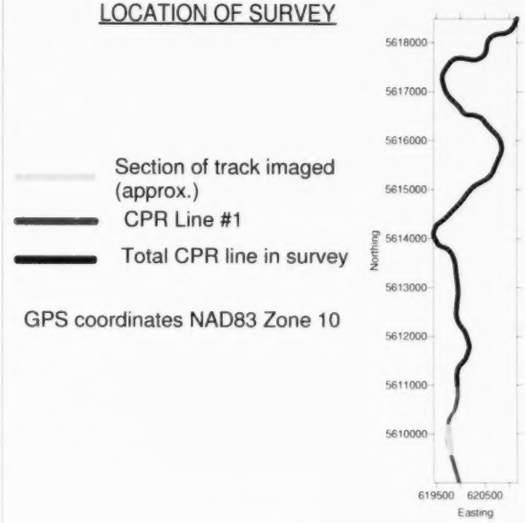
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 6: CPR1_2_1: 250 MHz GPR Data
Mile 55.22 to Mile 55.40



LOCATION OF SURVEY



Section of track imaged (approx.)

CPR Line #1

Total CPR line in survey

GPS coordinates NAD83 Zone 10

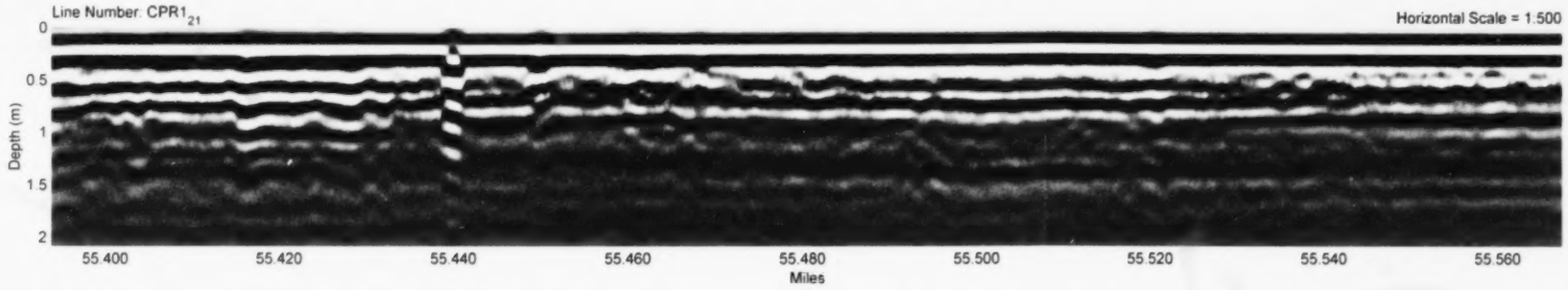
LEGEND

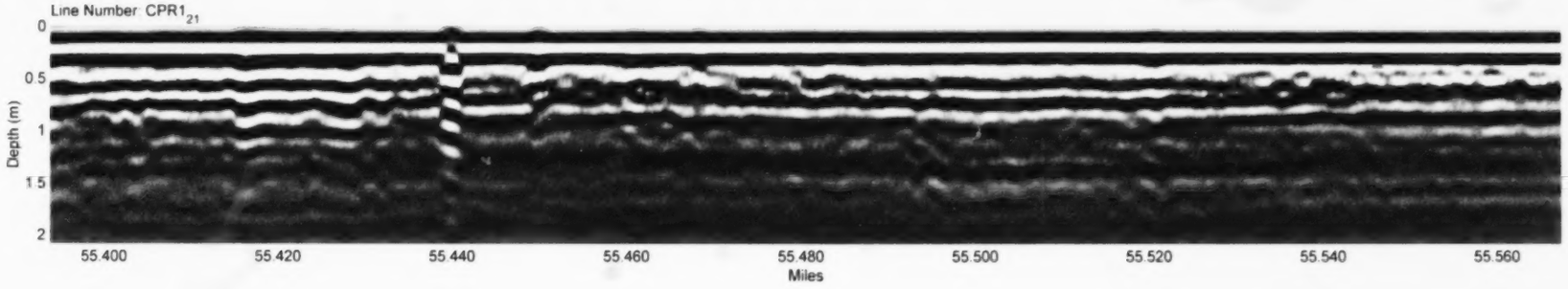
Interpreted base of ballast
Interpreted base of sub-ballast

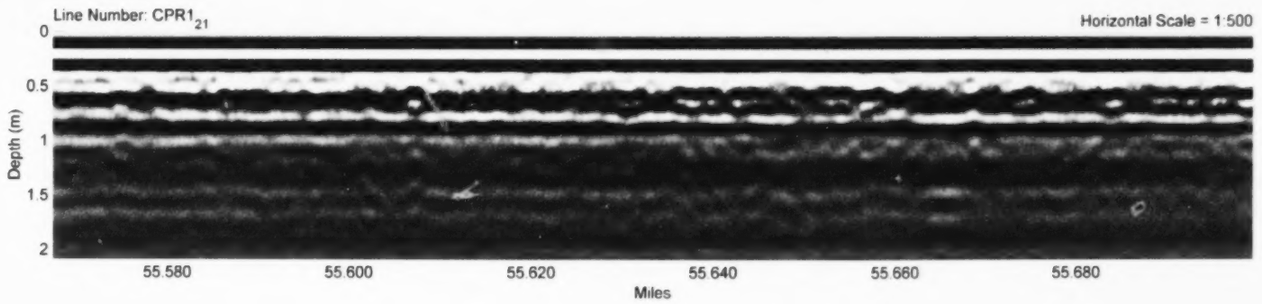
IMC
Associated Mining Consultants Ltd.

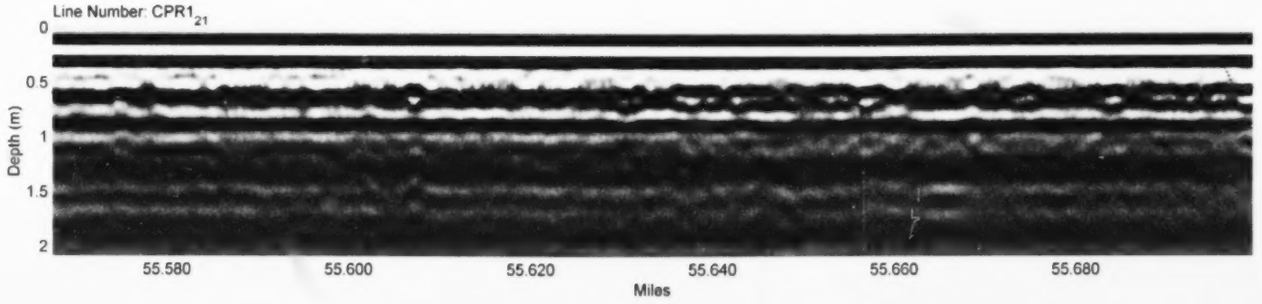
Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 7: CPR1_2_1: 250 MHz GPR Data
Mile 55.4 to Mile 55.70

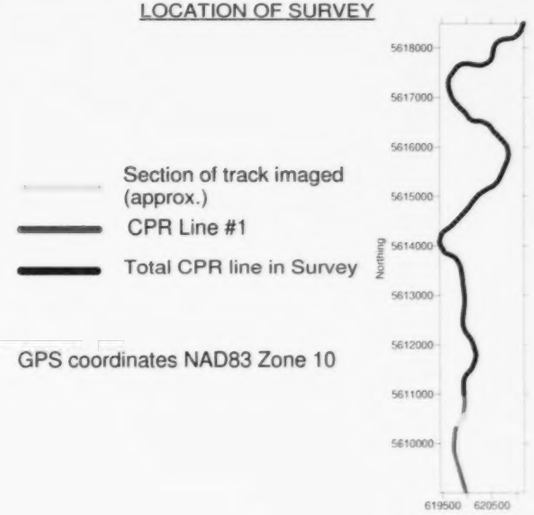








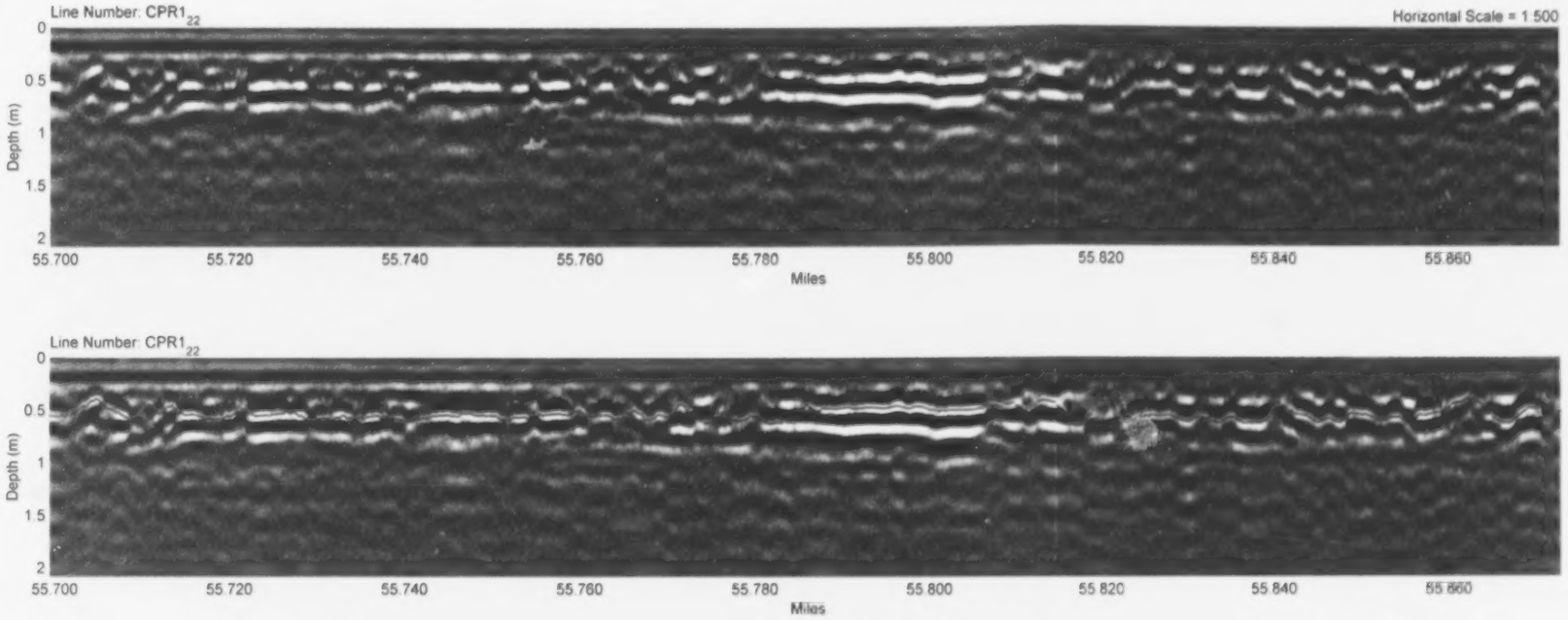
LOCATION OF SURVEY

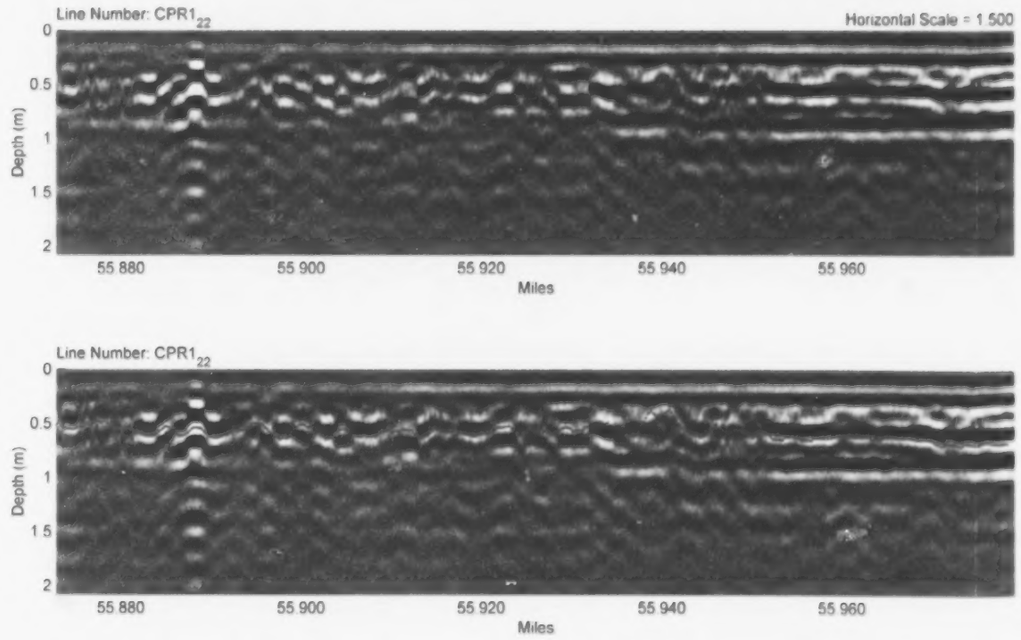


LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.

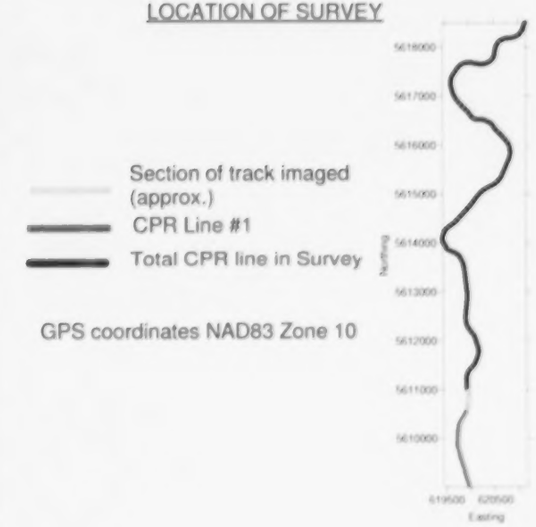




Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 8: CPR1_2b: 250 MHz GPR Data
Mile 55.7 to Mile 55.98

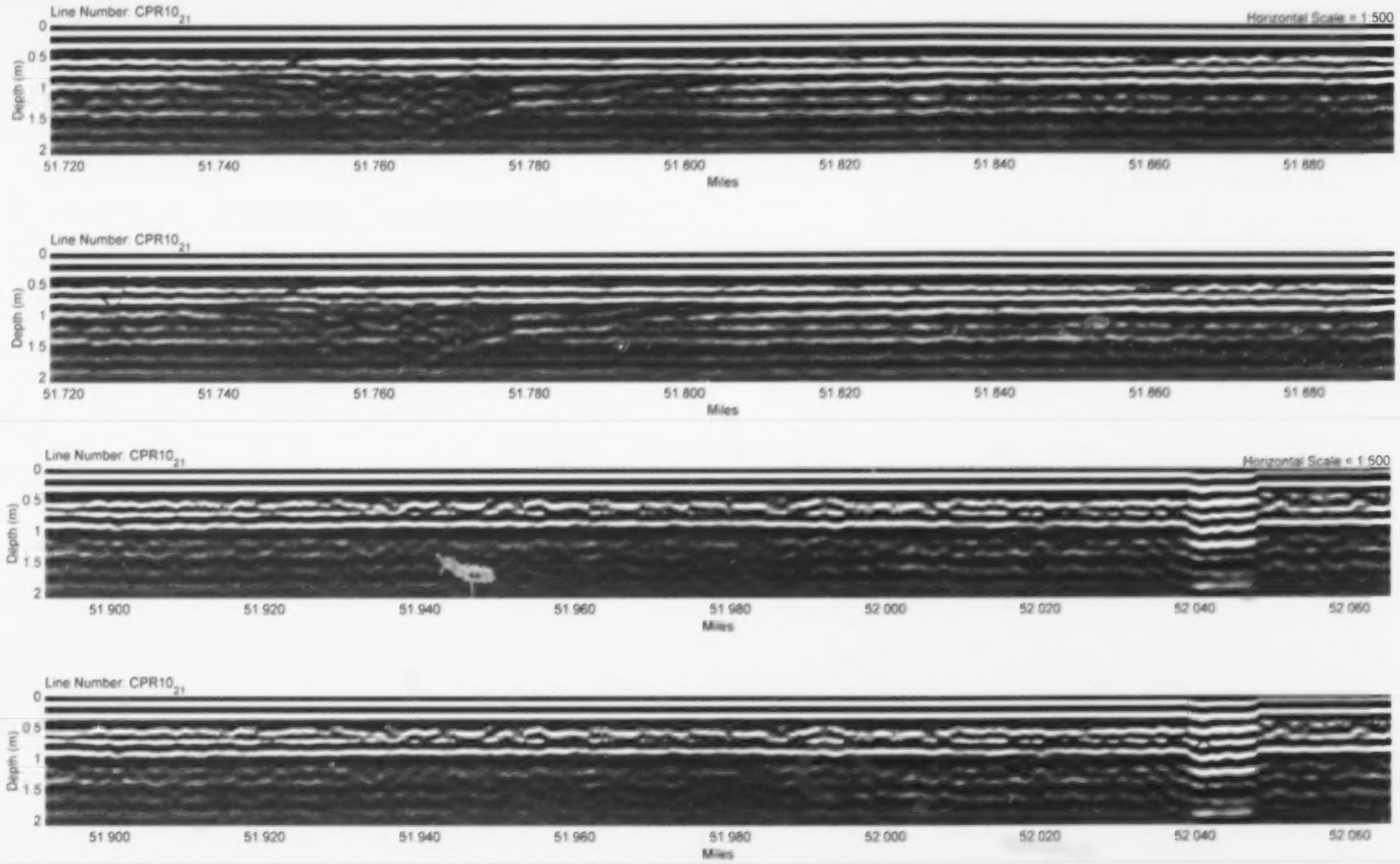
LOCATION OF SURVEY



LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

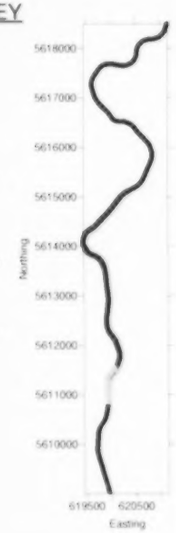
IMC
Associated Mining Consultants Ltd.



Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 9: CPR10_2_1a: 250MHz GPR Data
Mile 51.72 to Mile 52.24

LOCATION OF SURVEY



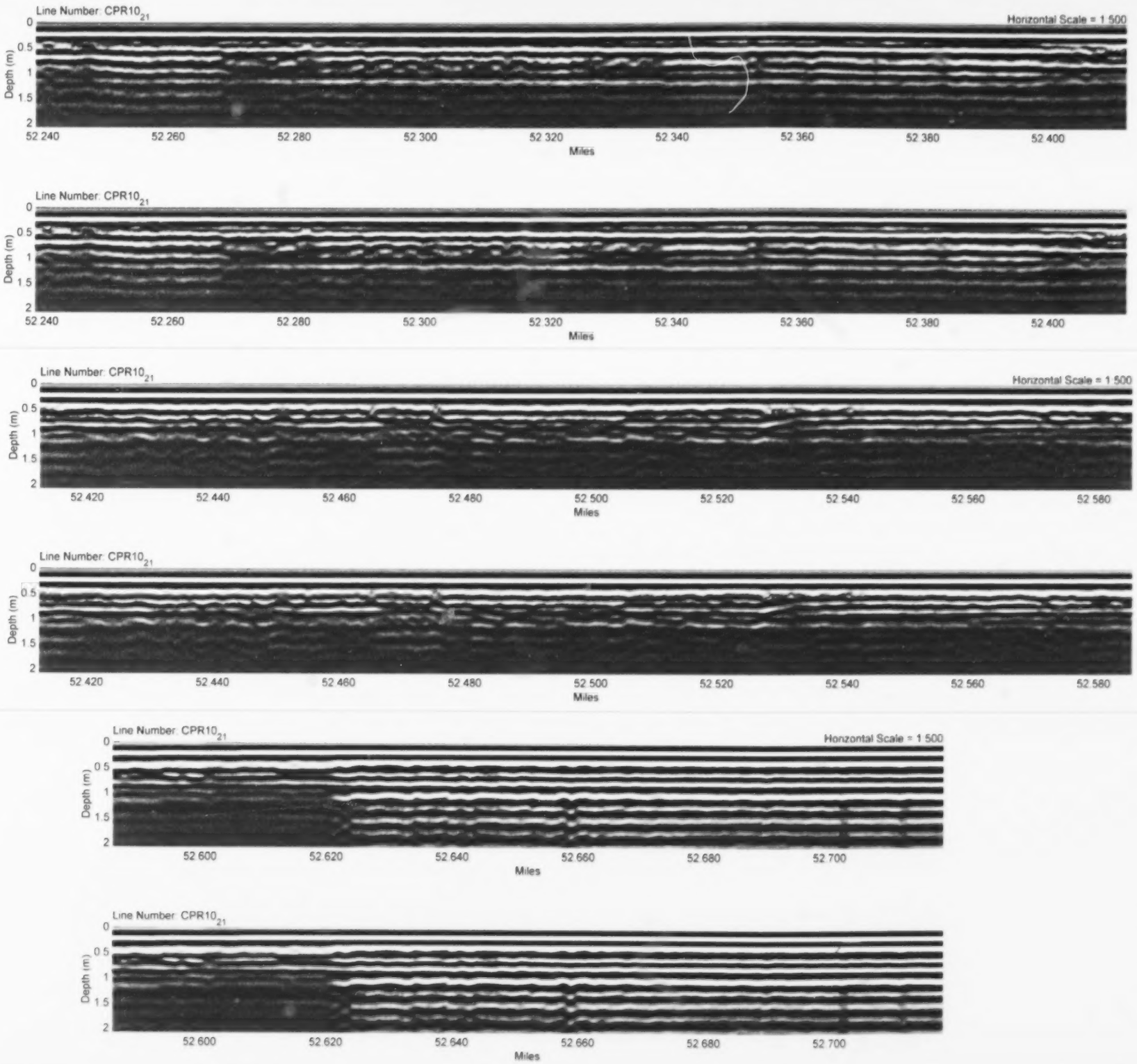
Section of track imaged (approx.)
CPR Line #10
Total CPR line in survey

GPS coordinates NAD83 Zone 10

LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

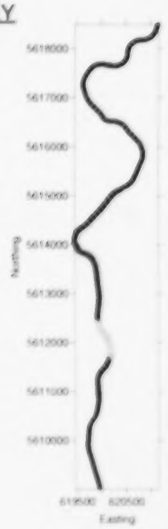
IMC
Associated Mining Consultants Ltd.



Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 10: CPR10_2_1b: 250 MHz GPR Data
Mile 52.24 to Mile 52.72

LOCATION OF SURVEY



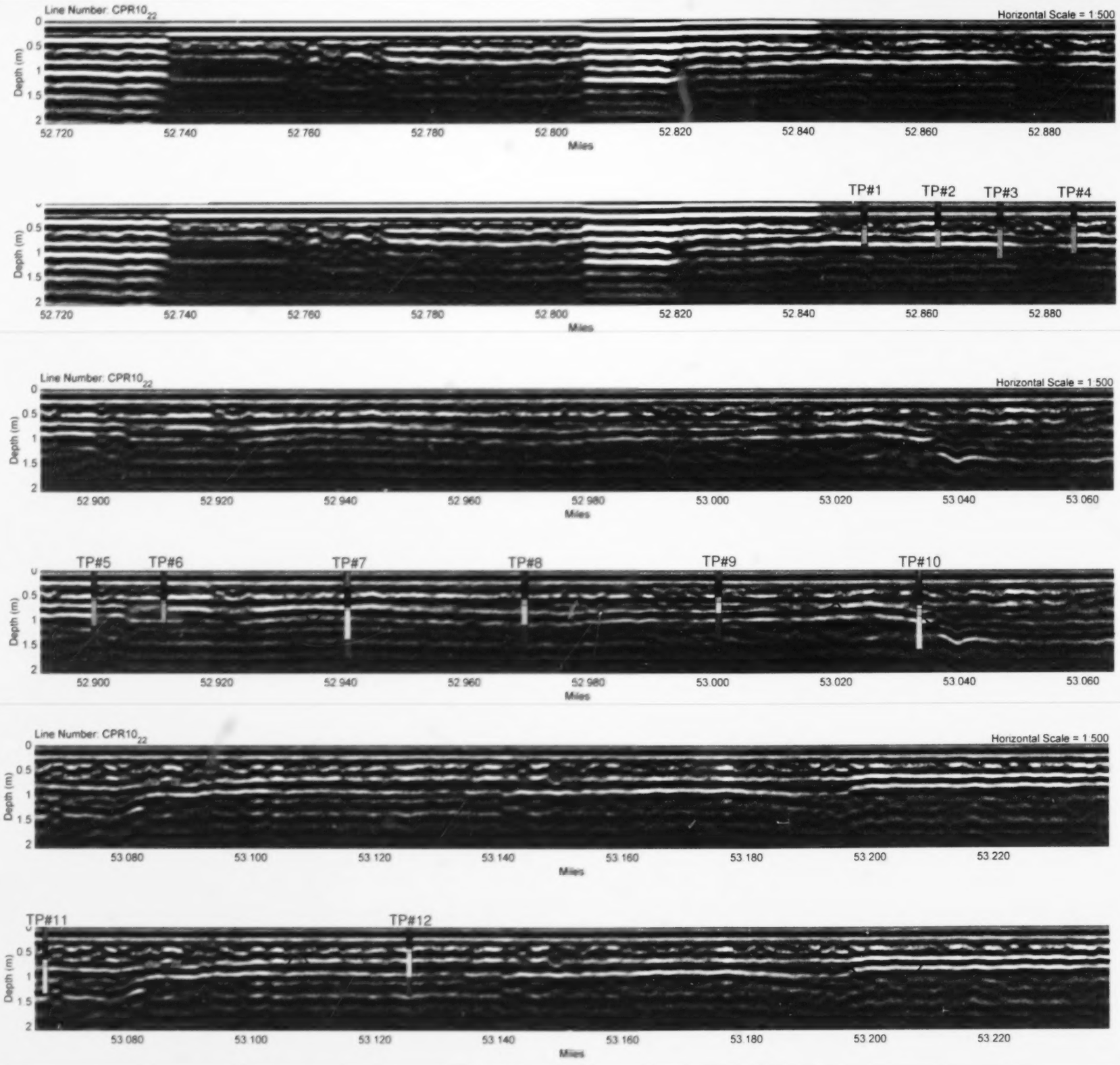
Section of track imaged (approx.)
CPR Line #10
Total CPR line in survey

GPS coordinates NAD83 Zone 10

LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.



Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 11: CPR10_2_2a: 250 MHz GPR Data
Mile 52.7 to Mile 53.24

LOCATION OF SURVEY

Section of track imaged (approx.)
CPR Line #10
Total CPR line in survey

GPS coordinates NAD83 Zone 10

RADAR LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

TEST PIT DATA LEGEND

BALLAST. LIGHT TO MEDIUM-GREY, COARSE ANGULAR GRAVEL. APPROX. NOM. DIAM. = 2.4cm

BALLAST. ANGULAR TO SUB-ANGULAR GRAVEL. MEDIUM TO DARK-GREY, LOCALLY OXIDIZED TO ORANGE-BROWN COLOUR. TRACE LOOSELY-PACKED MATRIX OF SOOTY TO OILY SILTY-FINE SAND MIXED WITH A VARIETY OF RAIL BED DETRITUS, ORGANICS AND WOOD SPLINTERS. APPROX. NOM. DIAM. = 2.2cm

SUB-BALLAST. SUB-ANGULAR TO SUB-ROUNDED GRAVEL AND SAND. DARK GREYISH-BROWN MIXTURE OF FINE TO COARSE GRAVEL, WITH A LOOSELY-PACKED SANDY MATRIX, LOCALLY CONTAINS A COMPONENT OF GRITTY COAL AND CRUSHED, FINE SLATEY-SHALE. GRAVEL PARTICLES LOCALLY OXIDIZED TO A YELLOWY-ORANGE/BROWN COLOUR. APPROX. NOM. DIAM. = 1.3cm

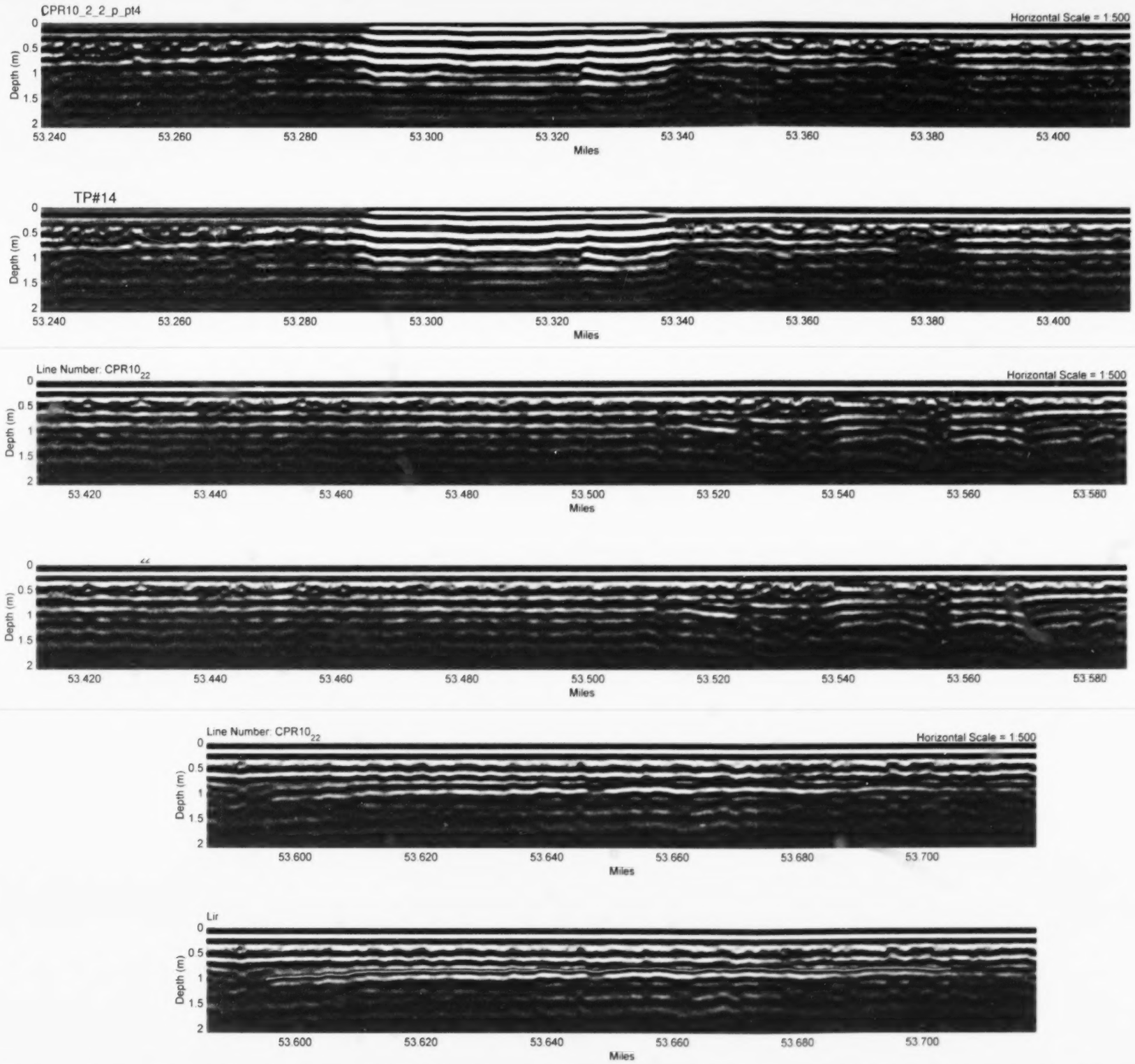
SUB-BALLAST. SUB-ROUNDED TO ROUNDED FINE GRAVEL AND SAND. LIGHT MUDDY-GREY AND SILTY-CLAY COATING. TRACE COARSE GRAVEL MIXED WITH FINE GRAVEL LOCALLY. LOOSE GRITTY MATRIX OF 10-20% SILTY-SAND. APPROX. NOM. DIAM. = 1.2cm

GENERAL FILL. POORLY-GRADED SANDS, SILTY TO CLAYEY-SAND AND GRAVEL MIXTURES, CRUSHED SLATEY-SHALE HORIZONS, AND MIXTURES OF COARSE SAND, COAL AND RAILWAY-CINDER/DEBRIS. VARIABLE THICKNESSES AND DISTRIBUTION OF BEDS. LOCAL OXIDIZED SAND.

LOCAL NATIVE MATERIAL. LIGHT-GREY TO TAN SILTY-CLAY AND SILT WITH TRACE CLAY AND FINE SAND. SILTY-CLAY COMMONLY RHYTHMICALLY LAMINATED OR INTER-BEDDED WITH COARSE, ROUNDED SAND AND FINE GRAVEL HORIZONS.

(Test pit data and legend from BGC Engineering report 0087-032-09)

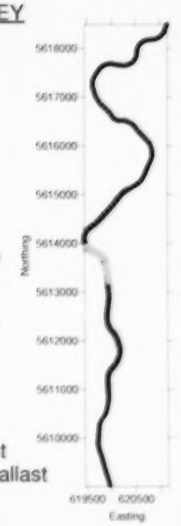
IMC
Associated Mining Consultants Ltd.



Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 12: CPR10_2_2b: 250 MHz GPR Data
Mile 53.24 to Mile 53.72

LOCATION OF SURVEY



Section of track imaged (approx.)
CPR Line #10
Total CPR line in survey

GPS coordinates NAD83 Zone 10

RADAR LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast
Interpreted base of fill

TEST PIT LEGEND

BALLAST: LIGHT TO MEDIUM-GREY, COARSE ANGULAR GRAVEL. APPROX. NOM. DIAM. = 2.4cm

BALLAST: ANGULAR TO SUB-ANGULAR GRAVEL, MEDIUM TO DARK-GREY, LOCALLY OXIDIZED TO ORANGE-BROWN COLOUR, TRACE LOOSELY-PACKED MATRIX OF SOOTY TO OILY SILTY-FINE SAND MIXED WITH A VARIETY OF RAIL BED DETRITUS, ORGANICS AND WOOD SPLINTERS. APPROX. NOM. DIAM. = 2.2cm

SUB-BALLAST: SUB-ANGULAR TO SUB-ROUNDED GRAVEL AND SAND, DARK GREYISH-BROWN MIXTURE OF FINE TO COARSE GRAVEL, WITH A LOOSELY-PACKED SANDY MATRIX, LOCALLY CONTAINS A COMPONENT OF GRITTY COAL AND CRUSHED, FINE SLATEY-SHALE, GRAVEL PARTICLES LOCALLY OXIDIZED TO A YELLOWY-ORANGE/BROWN COLOUR. APPROX. NOM. DIAM. = 1.3cm

SUB-BALLAST: SUB-ROUNDED TO ROUNDED FINE GRAVEL AND SAND, LIGHT MUDDY-GREY AND SILTY-CLAY COATING, TRACE COARSE GRAVEL MIXED WITH FINE GRAVEL LOCALLY. LOOSE GRITTY MATRIX OF 10-20% SILTY-SAND. APPROX. NOM. DIAM. = 1.2cm

GENERAL FILL: POORLY-GRADED SANDS, SILTY TO CLAYEY-SAND AND GRAVEL MIXTURES, CRUSHED SLATEY-SHALE HORIZONS, AND MIXTURES OF COARSE SAND, COAL AND RAILWAY-CINDER/DEBRIS. VARIABLE THICKNESSES AND DISTRIBUTION OF BEDS. LOCAL OXIDIZED SAND.

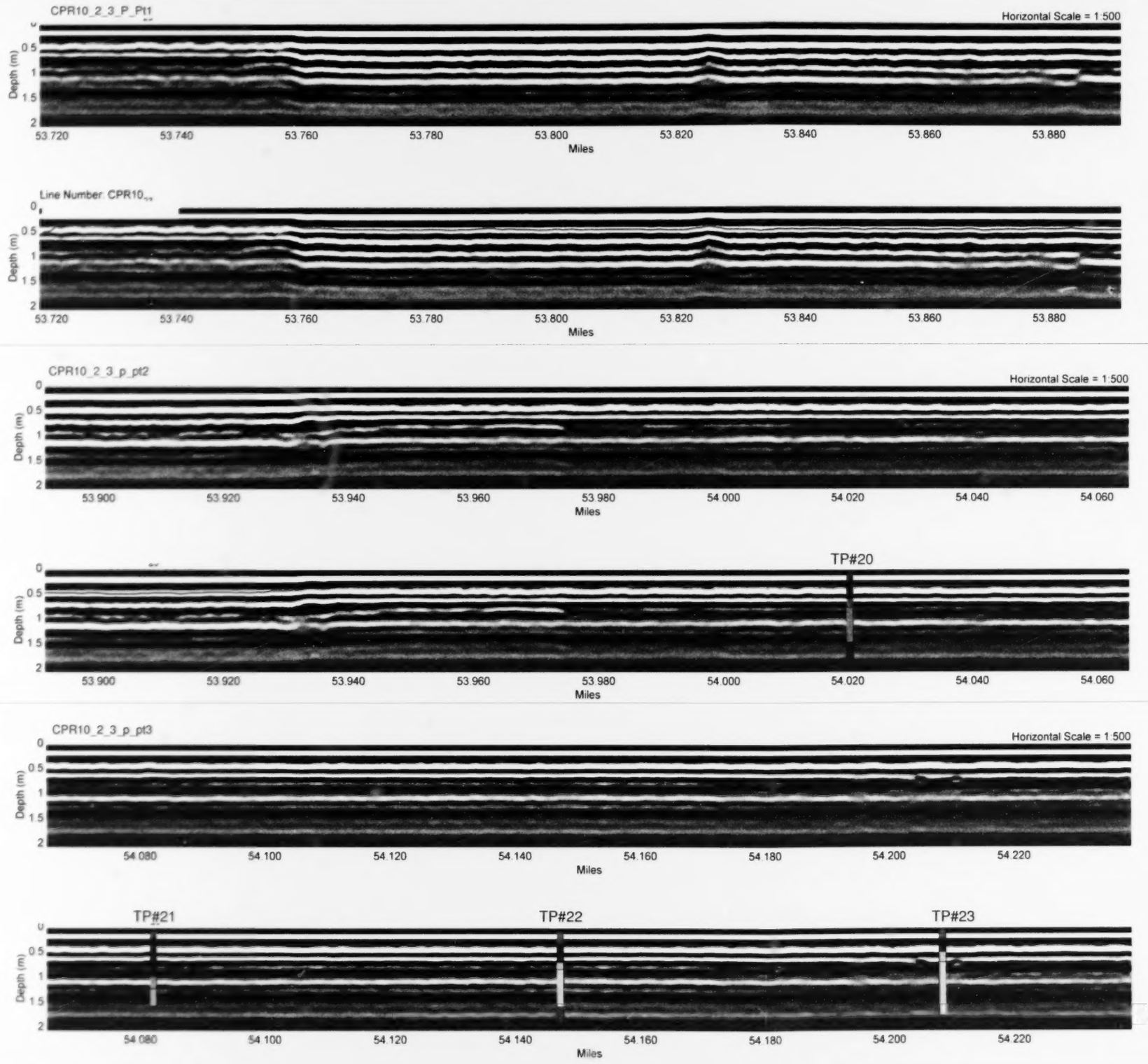
LOCAL NATIVE MATERIAL: LIGHT-GREY TO TAN SILTY-CLAY AND SILT WITH TRACE CLAY AND FINE SAND. SILTY-CLAY COMMONLY RHYTHMICALLY LAMINATED OR INTER-BEDDED WITH COARSE, ROUNDED SAND AND FINE GRAVEL HORIZONS.

(Test pit data and legend from BGC Engineering report 0087-032-09)

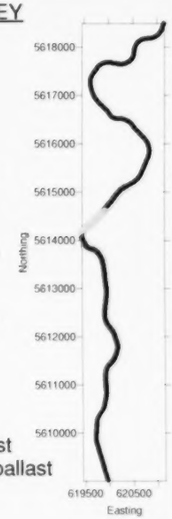
IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 13: CPR10_2_3a: 250 MHz GPR Data Mile 53.72 to Mile 54.24



LOCATION OF SURVEY



Section of track imaged (approx.)

CPR Line #10

Total CPR line in survey

GPS coordinates NAD83 Zone 10

RADAR LEGEND

Interpreted base of ballast

Interpreted base of sub-ballast

TEST PIT LEGEND

BALLAST. LIGHT TO MEDIUM-GREY, COARSE ANGULAR GRAVEL. APPROX. NOM. DIAM. = 2.4cm

BALLAST. ANGULAR TO SUB-ANGULAR GRAVEL. MEDIUM TO DARK-GREY, LOCALLY OXIDIZED TO ORANGE-BROWN COLOUR. TRACE LOOSELY-PACKED MATRIX OF SOOTY TO OILY SILTY-FINE SAND MIXED WITH A VARIETY OF RAIL BED DETRITUS, ORGANICS AND WOOD SPLINTERS. APPROX. NOM. DIAM. = 2.2cm

SUB-BALLAST. SUB-ANGULAR TO SUB-ROUNDED GRAVEL AND SAND. DARK GREYISH-BROWN MIXTURE OF FINE TO COARSE GRAVEL, WITH A LOOSELY-PACKED SANDY MATRIX, LOCALLY CONTAINS A COMPONENT OF GRITTY COAL AND CRUSHED, FINE SLATEY-SHALE GRAVEL PARTICLES LOCALLY OXIDIZED TO A YELLOWY-ORANGE/BROWN COLOUR. APPROX. NOM. DIAM. = 1.2cm

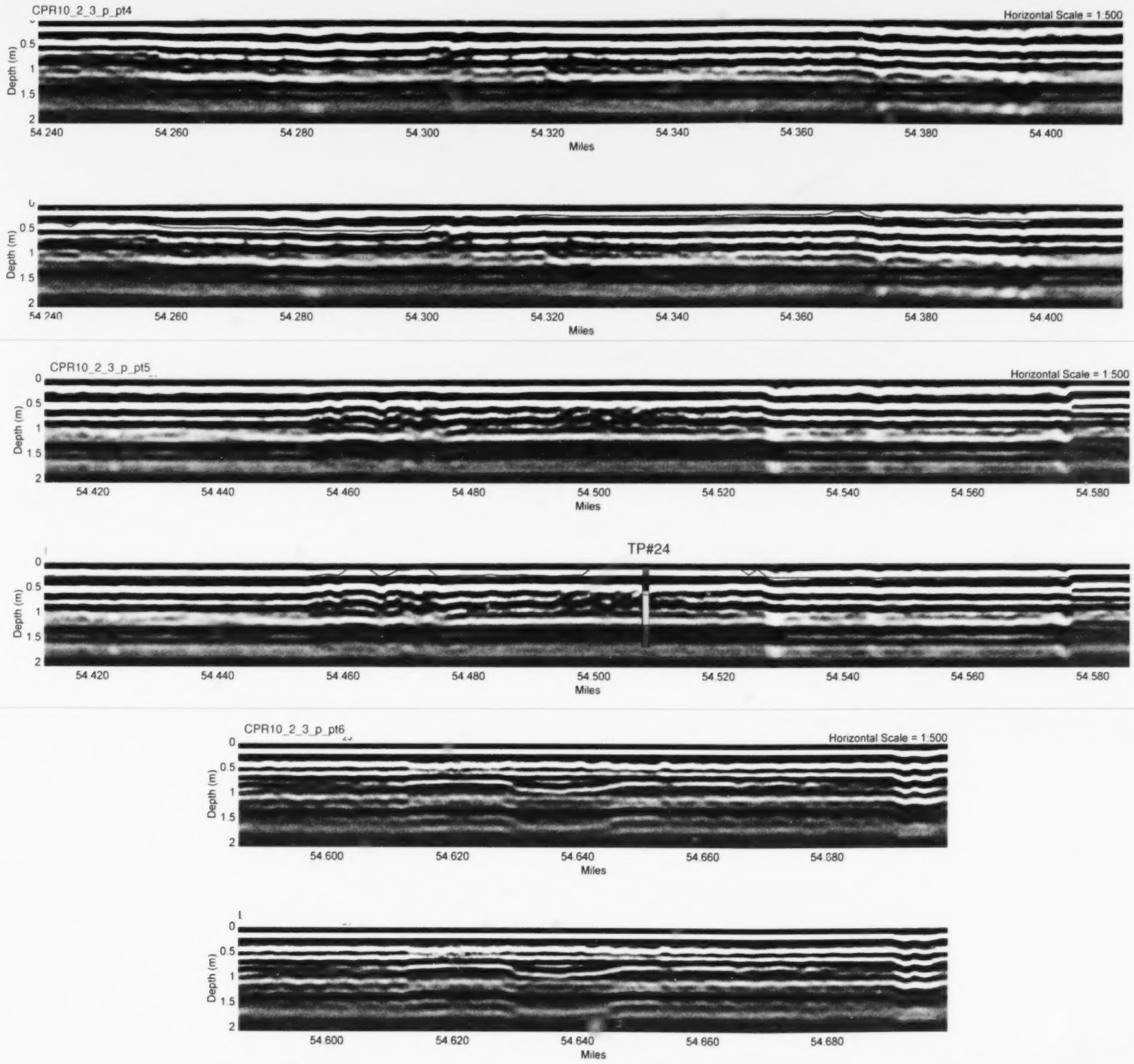
SUB-BALLAST. SUB-ROUNDED TO ROUNDED FINE GRAVEL AND SAND. LIGHT MUDDY-GREY AND SILTY-CLAY COATING. TRACE COARSE GRAVEL MIXED WITH FINE GRAVEL LOCALLY. LOOSE GRITTY MATRIX OF 10-20% SILTY-SAND. APPROX. NOM. DIAM. = 1.2cm

GENERAL FILL. POORLY-GRADED SANDS, SILTY TO CLAYEY-SAND AND GRAVEL MIXTURES, CRUSHED SLATEY-SHALE HORIZONS, AND MIXTURES OF COARSE SAND, COAL AND RAILWAY-CINDER/DEBRIS. VARIABLE THICKNESSES AND DISTRIBUTION OF BEDS. LOCAL OXIDIZED SAND.

LOCAL NATIVE MATERIAL. LIGHT-GREY TO TAN SILTY-CLAY AND SILT WITH TRACE CLAY AND FINE SAND. SILTY-CLAY COMMONLY RHYTHMICALLY LAMINATED OR INTER-BEDDED WITH COARSE, ROUNDED SAND AND FINE GRAVEL HORIZONS.

(Test pit data and legend from BGCEngineering report 0087-032-09)

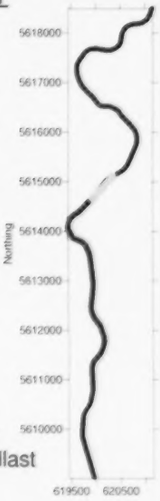
IMC
Associated Mining Consultants Ltd.



Ballast Investigation Ground-Penetrating Radar CPR Rail Line, Ashcroft, B.C.

FIG. 14: CPR10_2_3b: 250 MHz GPR Data Mile 54.24 to Mile 54.70

LOCATION OF SURVEY



Section of track imaged (approx.)
CPR Line #10
Total CPR line in survey

GPS coordinates NAD83 Zone 10

RADAR LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

TEST PIT LEGEND

BALLAST, LIGHT TO MEDIUM-GREY, COARSE ANGULAR GRAVEL. APPROX. NOM. DIAM. = 2.4cm

BALLAST, ANGULAR TO SUB-ANGULAR GRAVEL, MEDIUM TO DARK-GREY, LOCALLY OXIDIZED TO ORANGE-BROWN COLOUR. TRACE LOOSELY-PACKED MATRIX OF SOOTY TO OILY SILTY-FINE SAND MIXED WITH A VARIETY OF RAIL BED DETRITUS, ORGANICS AND WOOD SPLINTERS. APPROX. NOM. DIAM. = 2.2cm

SUB-BALLAST, SUB-ANGULAR TO SUB-ROUNDED GRAVEL AND SAND, DARK GREYISH-BROWN MIXTURE OF FINE TO COARSE GRAVEL, WITH A LOOSELY-PACKED SANDY MATRIX, LOCALLY CONTAINS A COMPONENT OF GRITTY COAL AND CRUSHED, FINE SLATEY-SHALE. GRAVEL PARTICLES LOCALLY OXIDIZED TO A YELLOWY-ORANGE/BROWN COLOUR. APPROX. NOM. DIAM. = 1.2cm

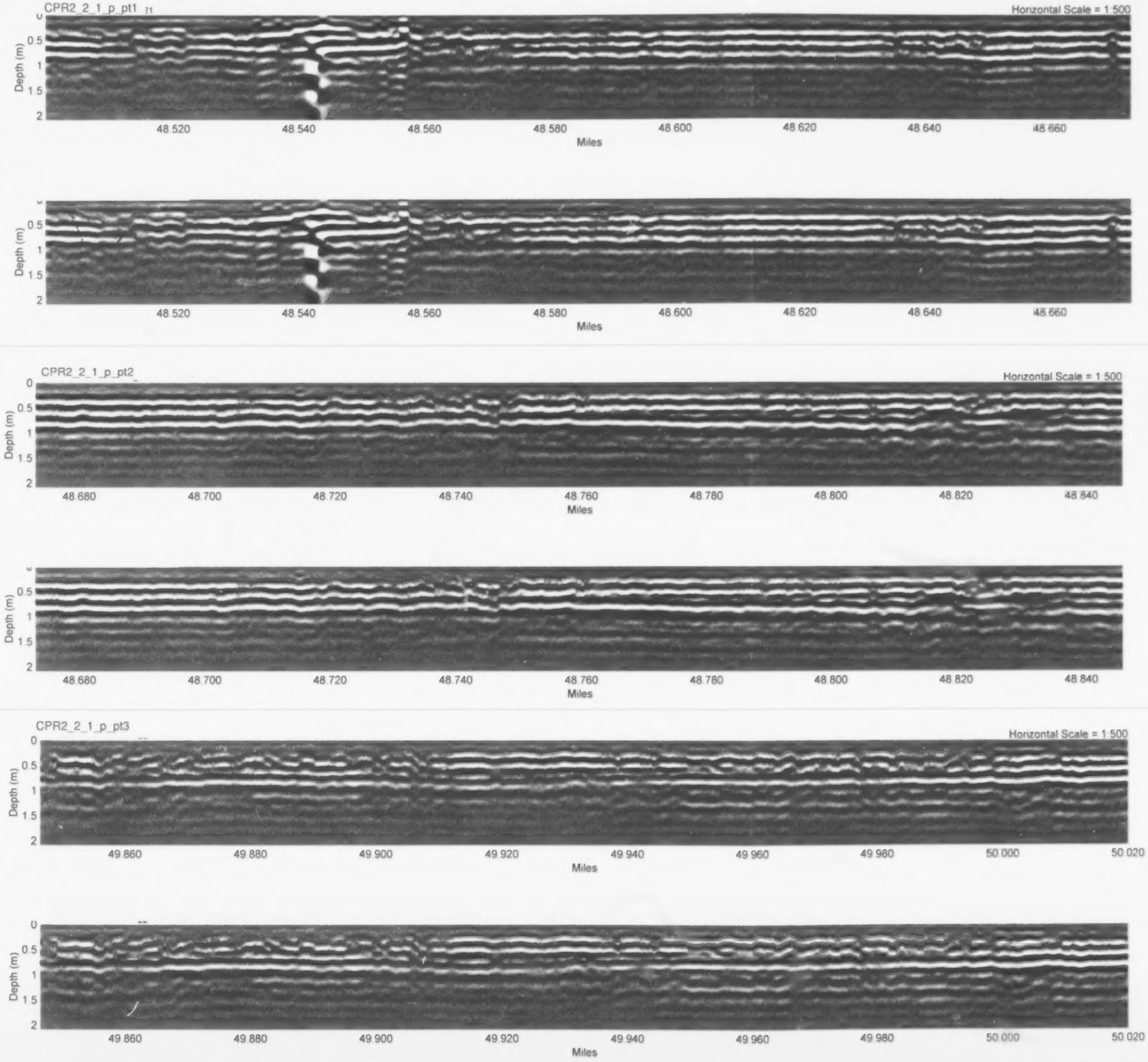
SUB-BALLAST, SUB-ROUNDED TO ROUNDED FINE GRAVEL AND SAND, LIGHT MUDDY-GREY AND SILTY-CLAY COATING. TRACE COARSE GRAVEL MIXED WITH FINE GRAVEL LOCALLY, LOOSE GRITTY MATRIX OF 10-20% SILTY-SAND. APPROX. NOM. DIAM. = 1.2cm

GENERAL FILL, POORLY-GRADED SANDS, SILTY TO CLAYEY-SAND AND GRAVEL MIXTURES, CRUSHED SLATEY-SHALE HORIZONS, AND MIXTURES OF COARSE SAND, COAL AND RAILWAY-CINDER/DEBRIS. VARIABLE THICKNESSES AND DISTRIBUTION OF BEDS. LOCAL OXIDIZED SAND.

LOCAL NATIVE MATERIAL, LIGHT-GREY TO TAN SILTY-CLAY AND SILT WITH TRACE CLAY AND FINE SAND. SILTY-CLAY COMMONLY RHYTHMICALLY LAMINATED OR INTER-BEDDED WITH COARSE, ROUNDED SAND AND FINE GRAVEL HORIZONS.

(Test pit data and legend from BGC Engineering report 0087-032-09)

IMC
Associated Mining Consultants Ltd.



Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 15: CPR2_2_1a: 250 MHz GPR Data
Mile 48.5 to Mile 49.02

LOCATION OF SURVEY

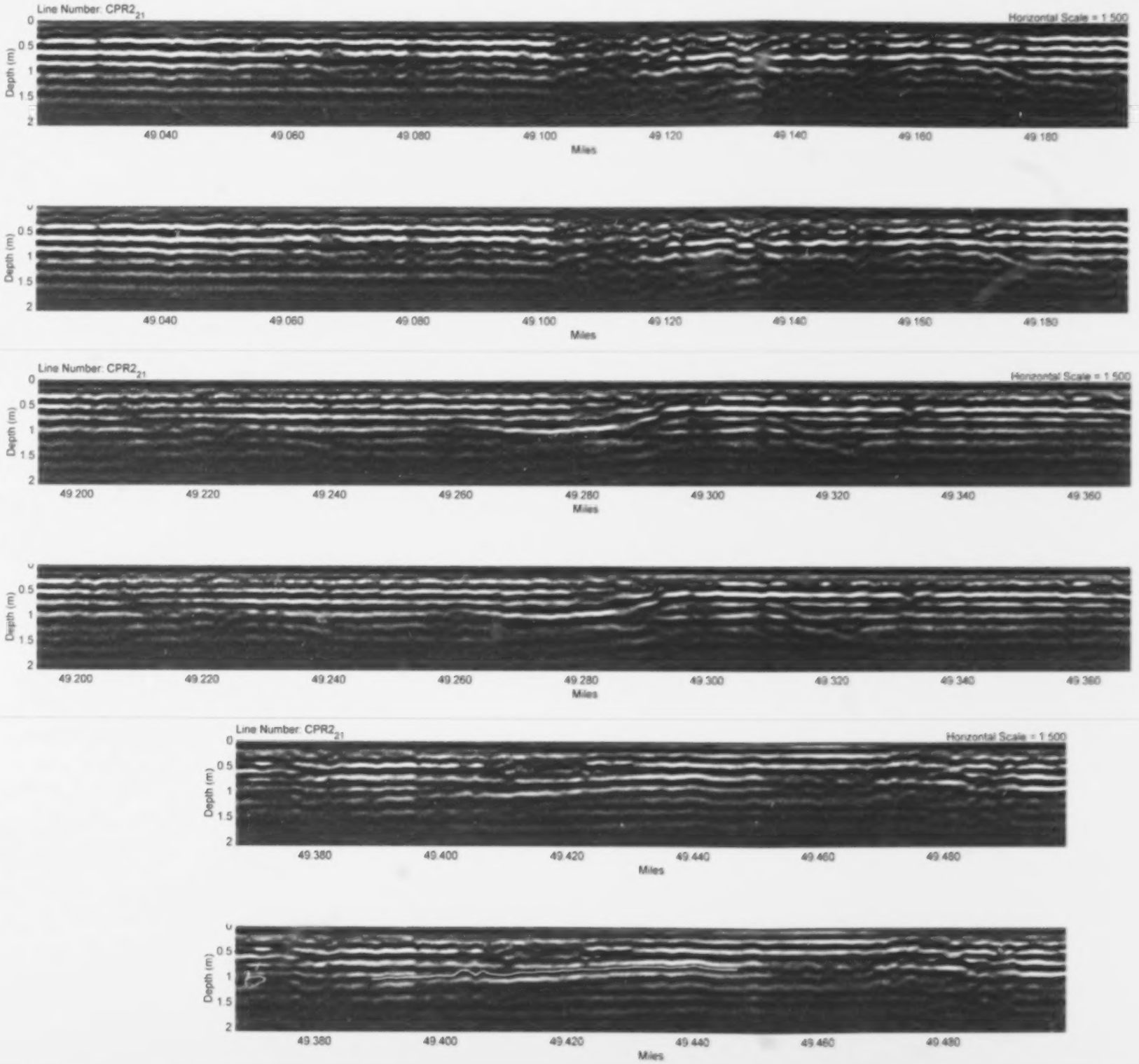
LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

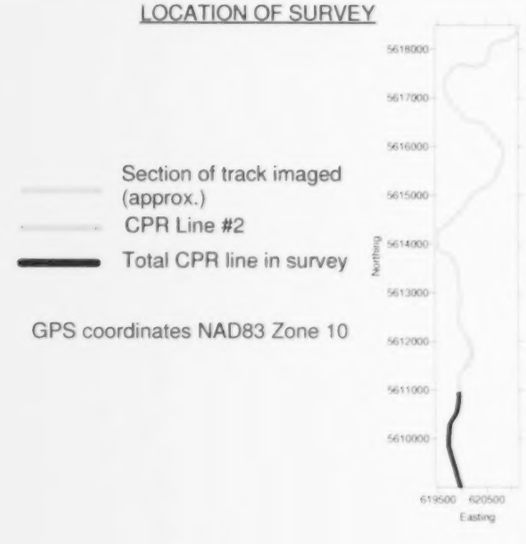
IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 16: CPR2_2_1b: 250 MHz GPR Data
Mile 49.02 to Mile 49.5



LOCATION OF SURVEY



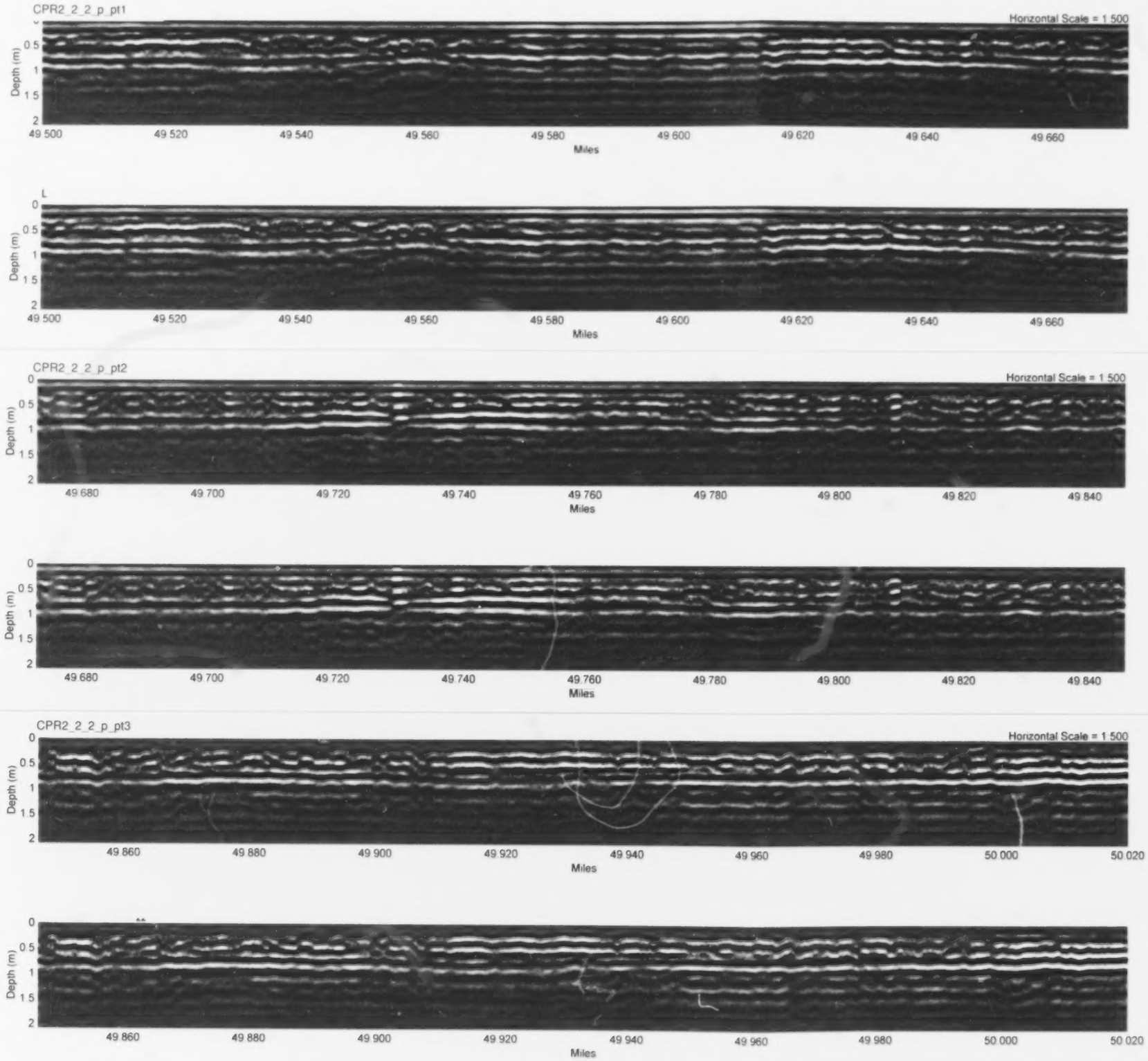
LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast
Interpreted base of fill

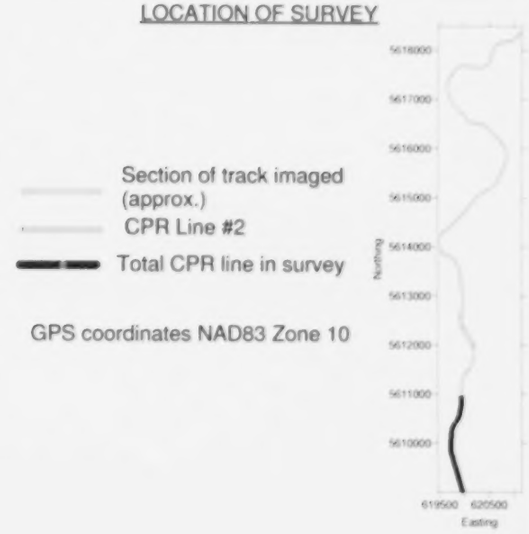
IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 17: CPR2_2_2a: 800 MHz GPR Data
Mile 49.5 to Mile 50.02



LOCATION OF SURVEY



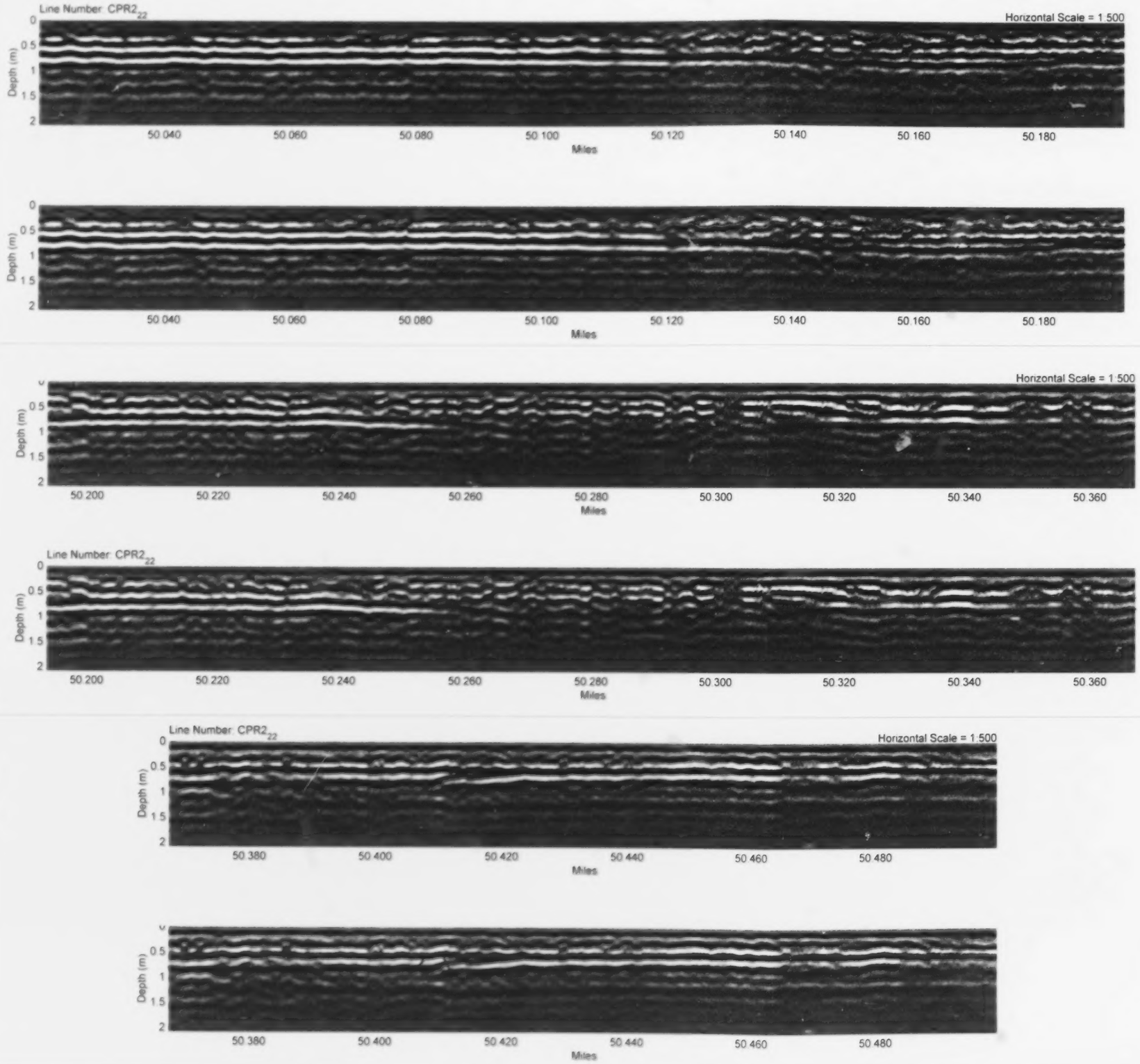
LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

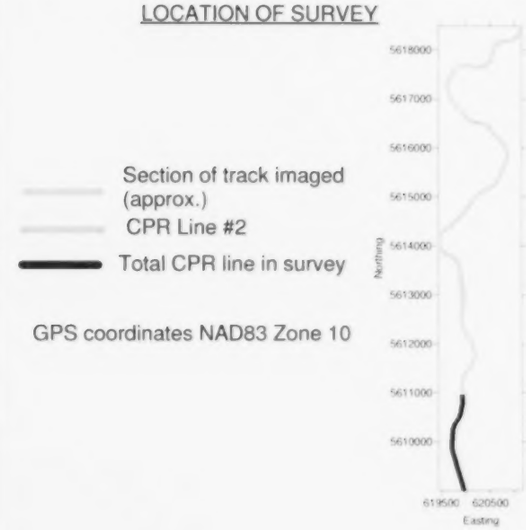
IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 18: CPR2_2_2b: 250 MHz GPR Data
Mile 50.02 to Mile 50.50



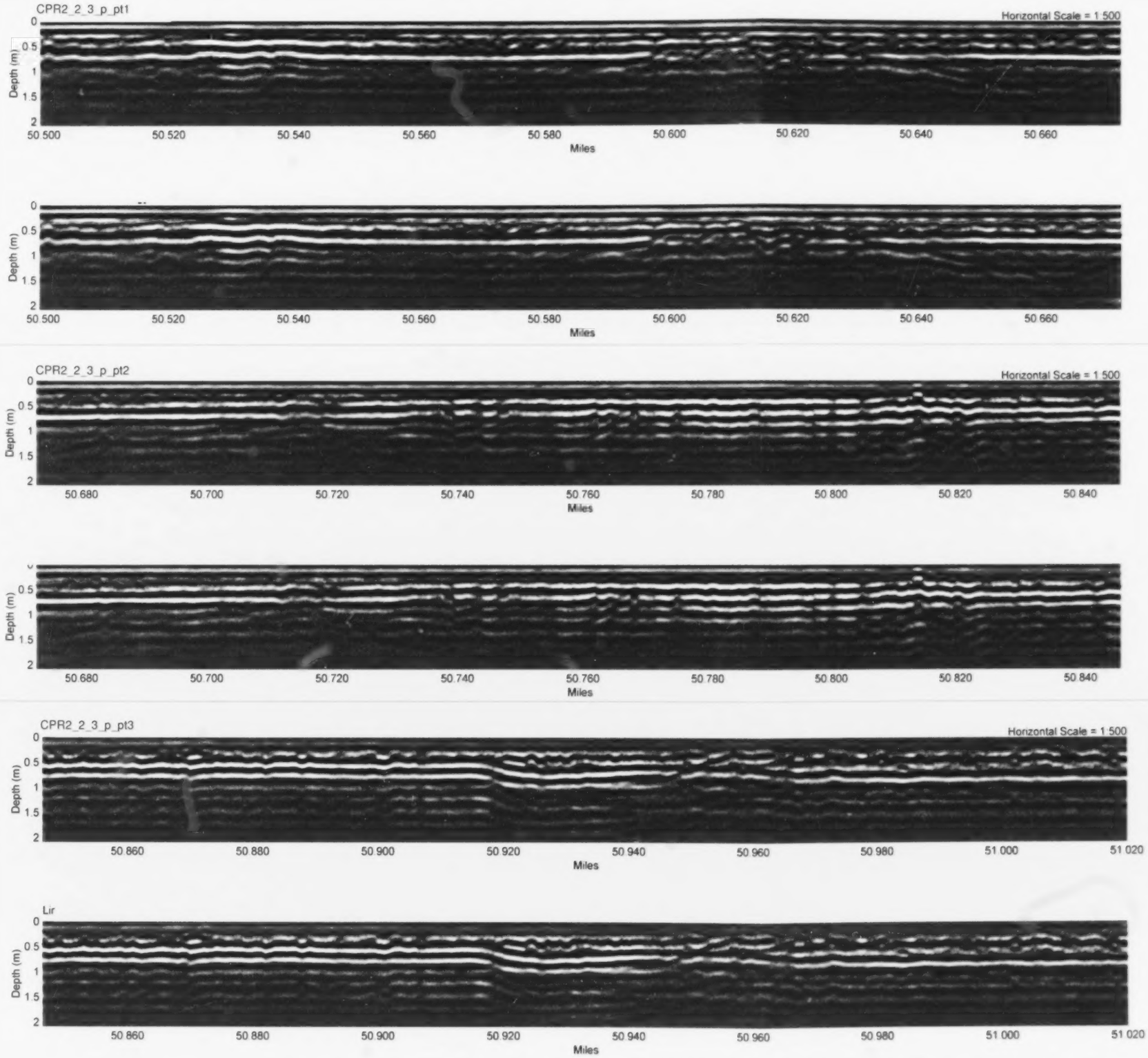
LOCATION OF SURVEY



LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.



Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 19: CPR2_2_3a: 250 MHz GPR Data
Mile 50.50 to Mile 51.02

LOCATION OF SURVEY

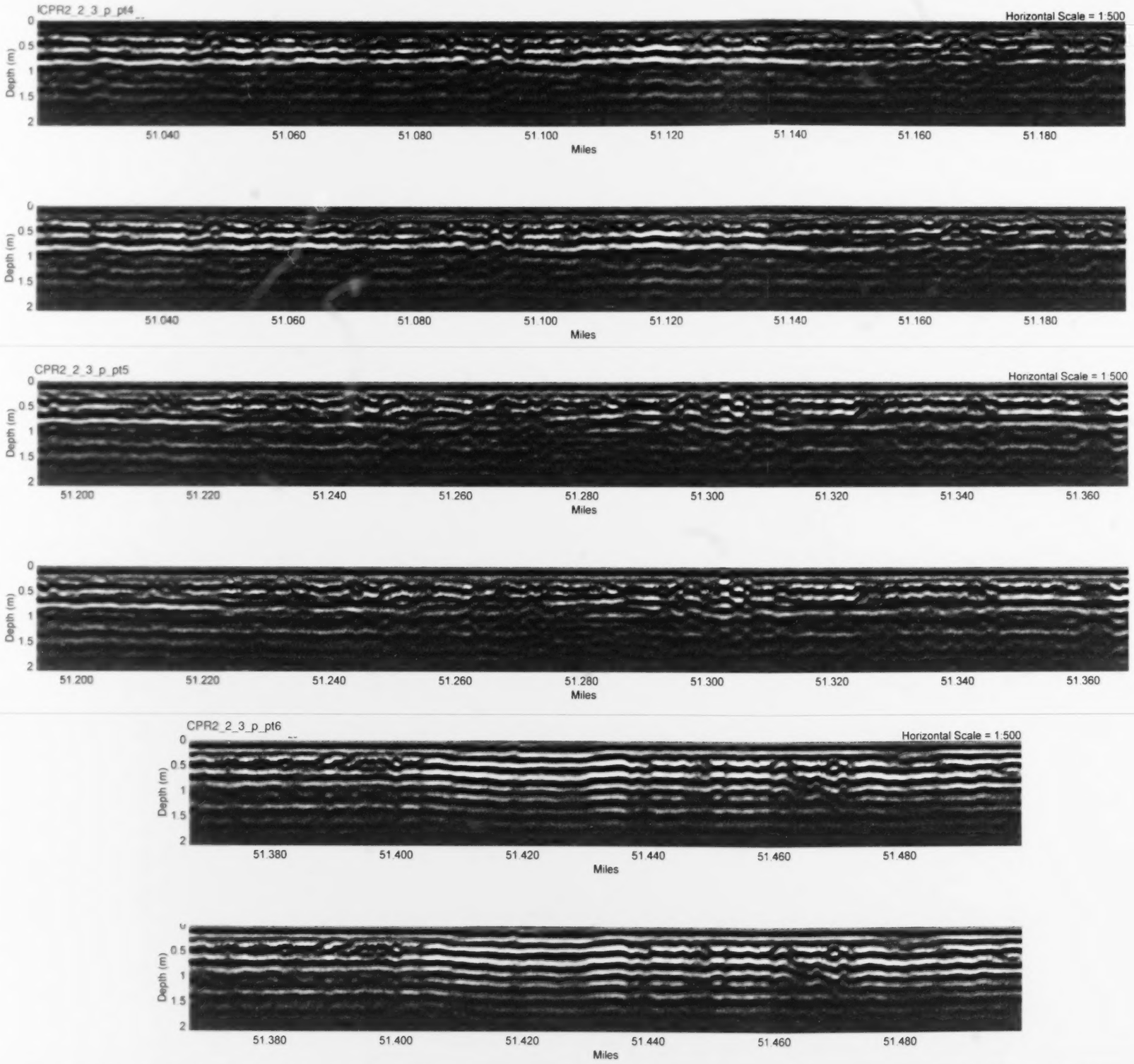
Section of track imaged (approx.)
CPR Line #2
Total CPR line in survey

GPS coordinates NAD83 Zone 10

LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

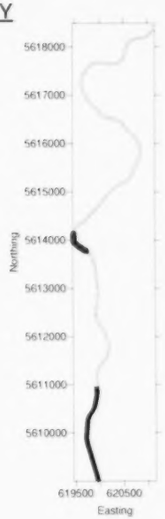
IMC
Associated Mining Consultants Ltd.



Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 20: CPR2_2_3b: 250 MHz GPR Data
Mile 51.02 to Mile 51.50

LOCATION OF SURVEY



Section of track imaged (approx.)
CPR Line #2
Other CPR line in survey

GPS coordinates NAD83 Zone 10

LEGEND

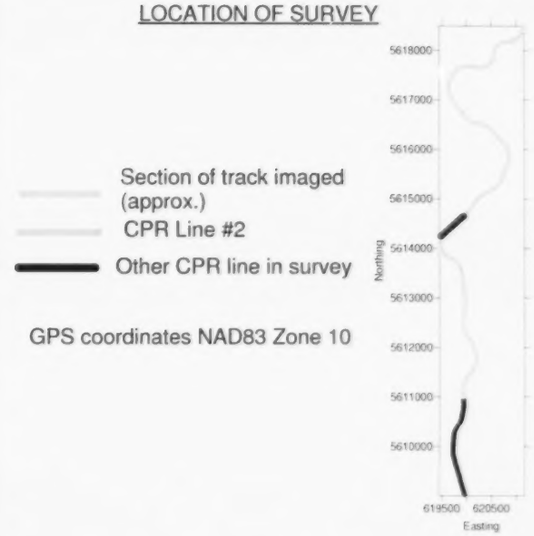
Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 21: CPR2_2_4a: 250 MHz GPR Data
Mile 51.50 to Mile 52.02

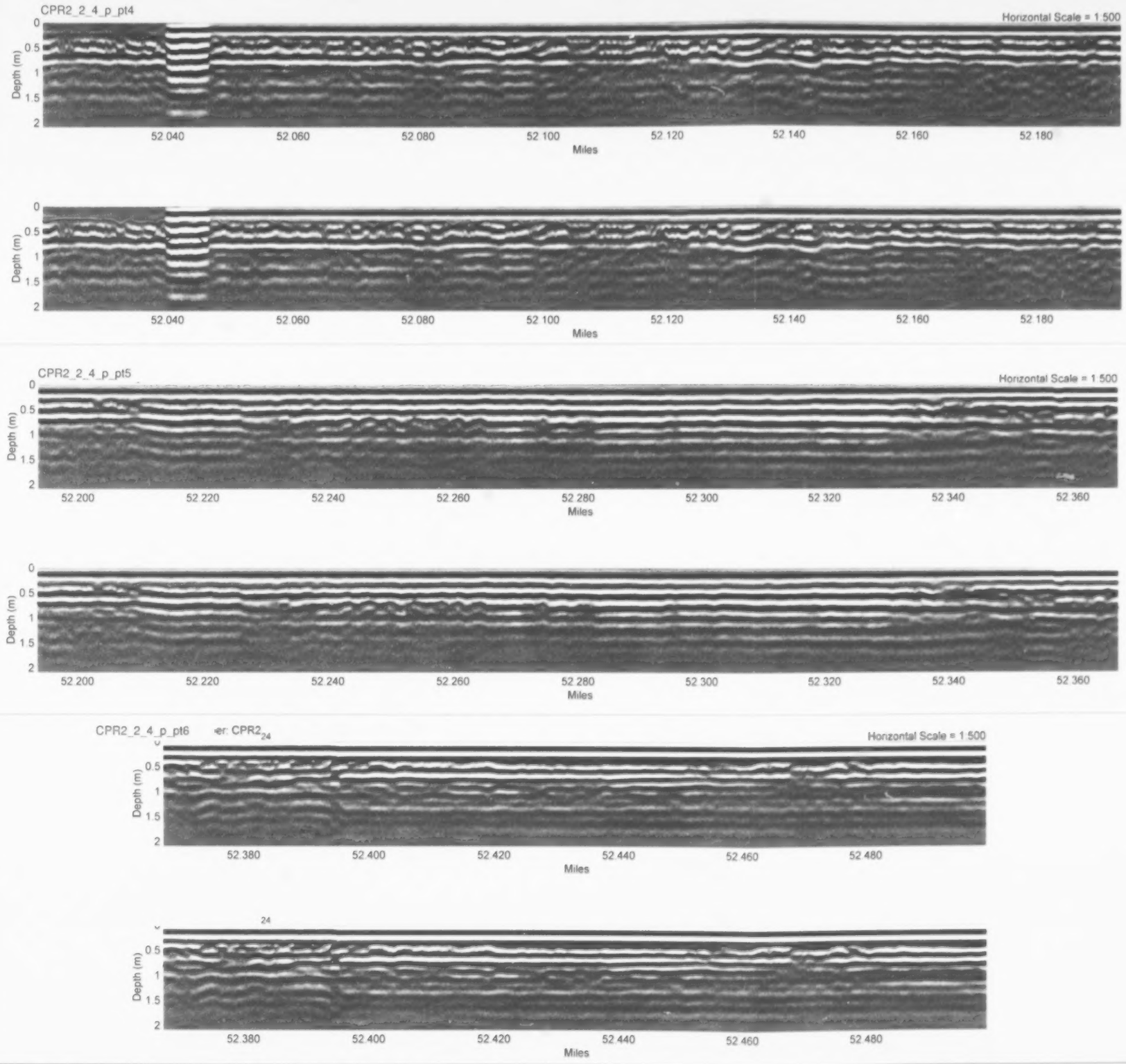
LOCATION OF SURVEY



LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast
Interpreted base of fill

IMC
Associated Mining Consultants Ltd.



Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 22: CPR2_2_4b: 250 MHz GPR Data
Mile 52.02 to Mile 52.50

LOCATION OF SURVEY

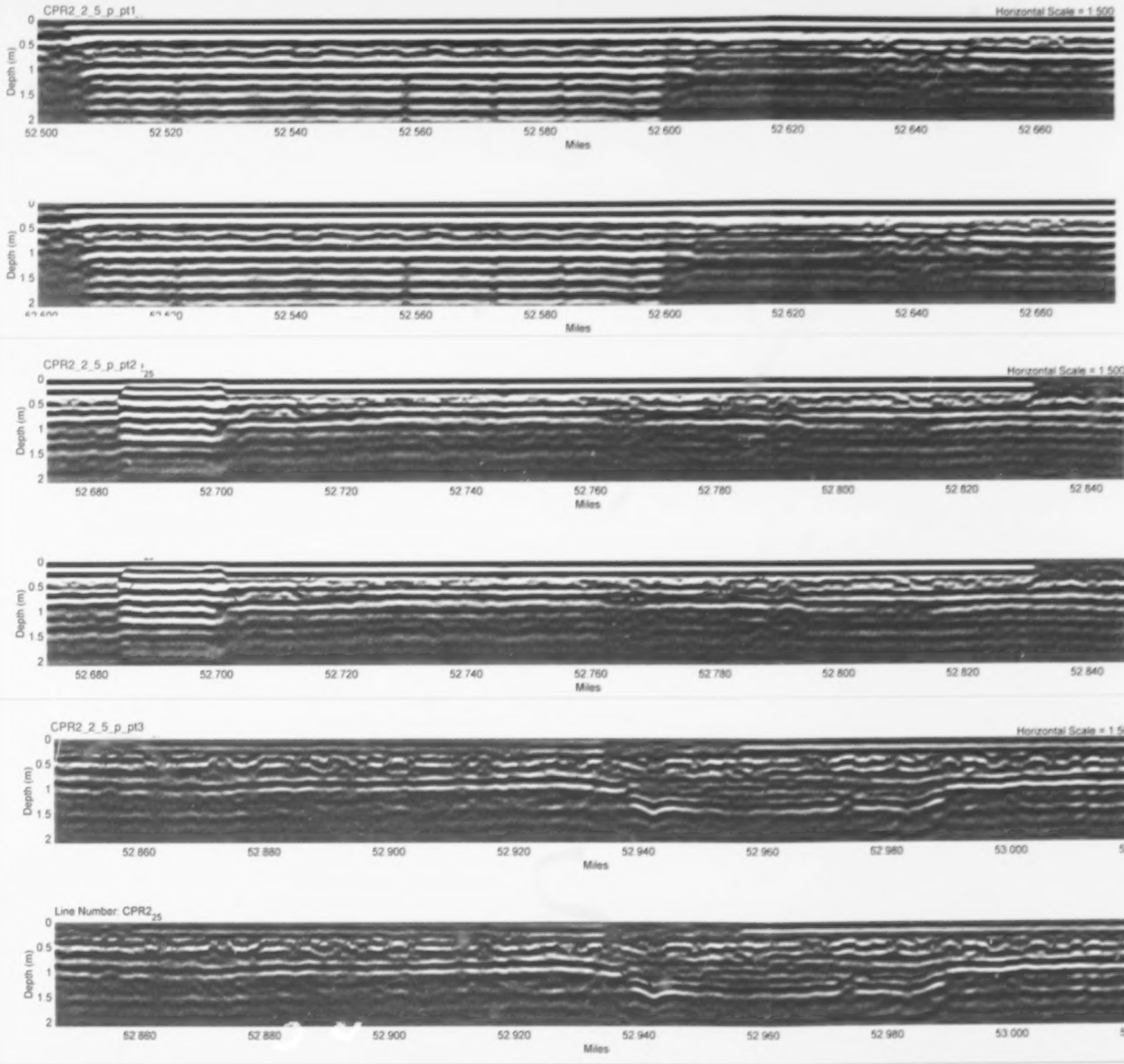
Section of track imaged (approx.)
CPR Line #2
Other CPR line in survey

GPS coordinates NAD83 Zone 10

LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.



Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 23: CPR2_2_5a: 250 MHz GPR Data
Mile 52.50 to Mile 53.02

LOCATION OF SURVEY

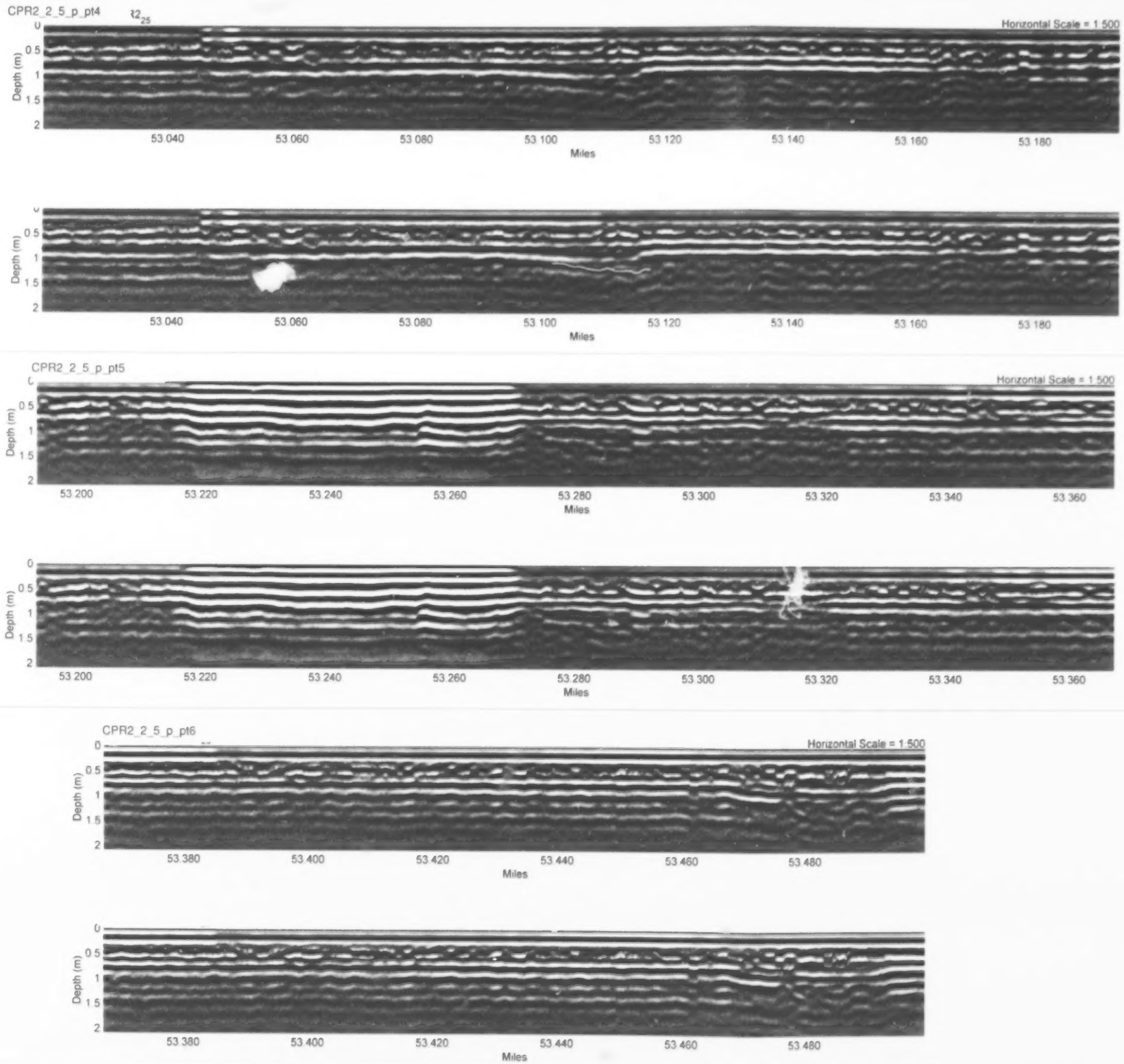
Section of track imaged (approx.)
CPR Line #2
Other CPR line in survey

GPS coordinates NAD83 Zone 10

LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.



Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 24: CPR2_2_5b: 250 MHz GPR Data
Mile 53.02 to Mile 53.50

LOCATION OF SURVEY

Section of track imaged (approx.)
CPR Line #2
Other CPR line in survey

GPS coordinates NAD83 Zone 10

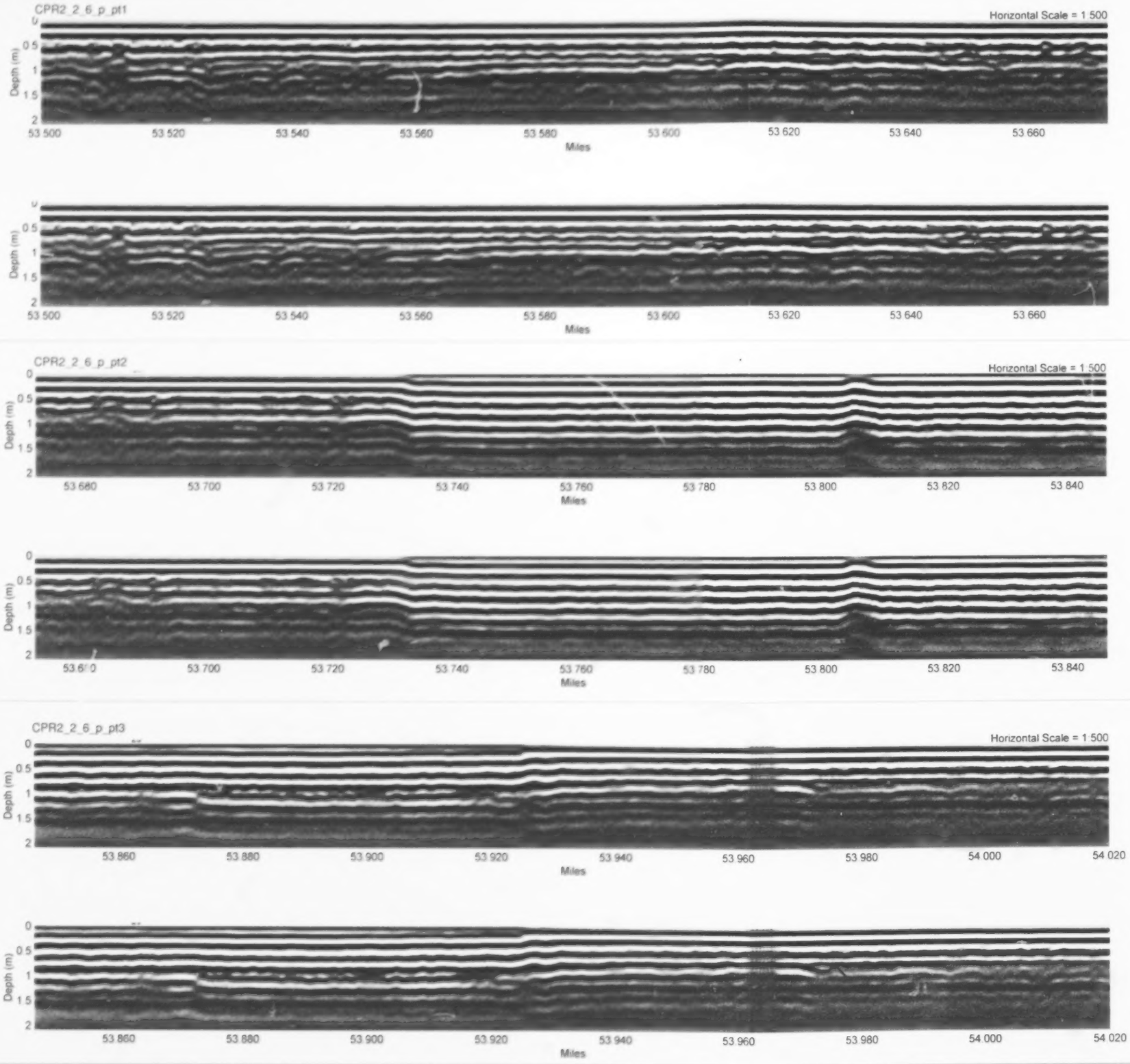
LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 25: CPR2_2_6a: 250 MHz GPR Data
Mile 53.50 to Mile 54.02



LOCATION OF SURVEY

Section of track imaged (approx.)
CPR Line #2
Other CPR line in survey

GPS coordinates NAD83 Zone 10

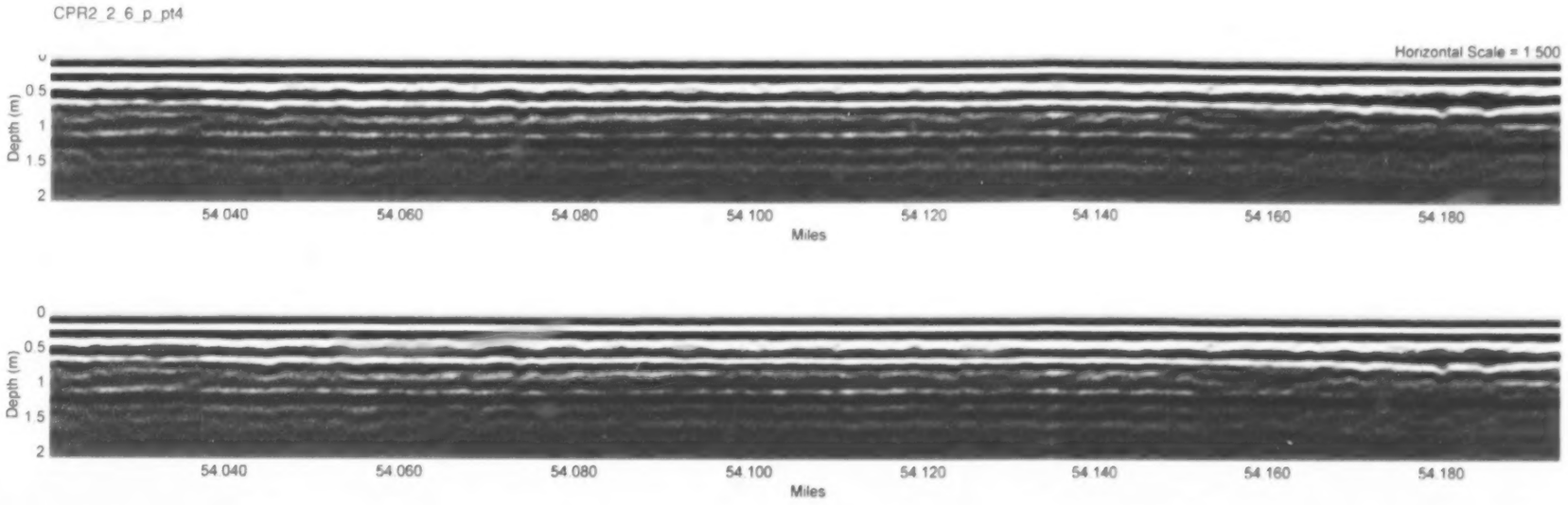
LEGEND

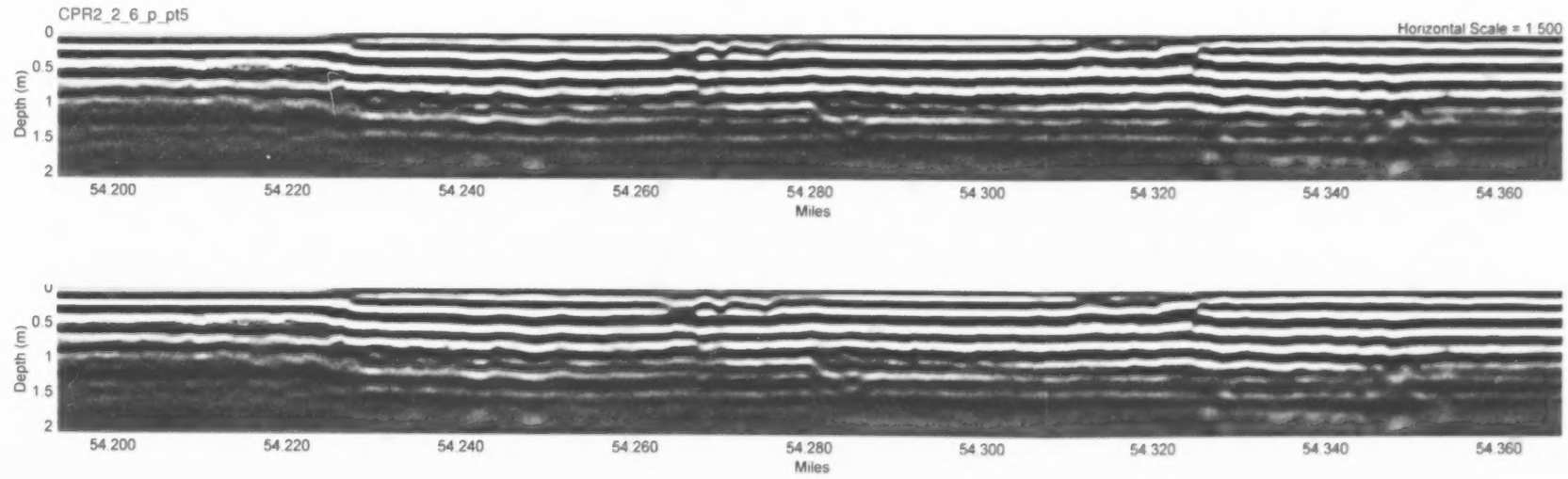
Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.

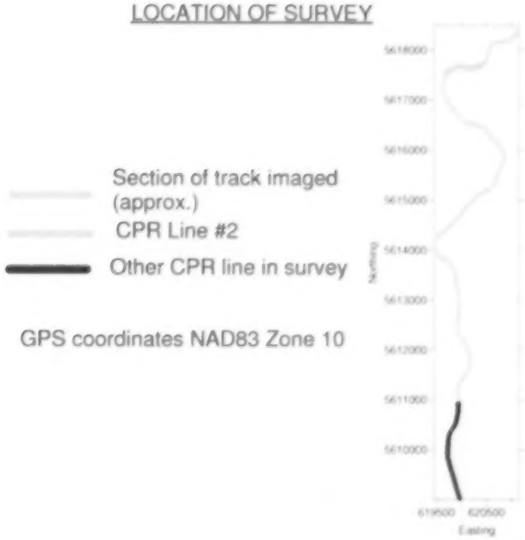
Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 26: CPR2_2_6b: 250 MHz GPR Data
Mile 54.02 to Mile 54.36





LOCATION OF SURVEY



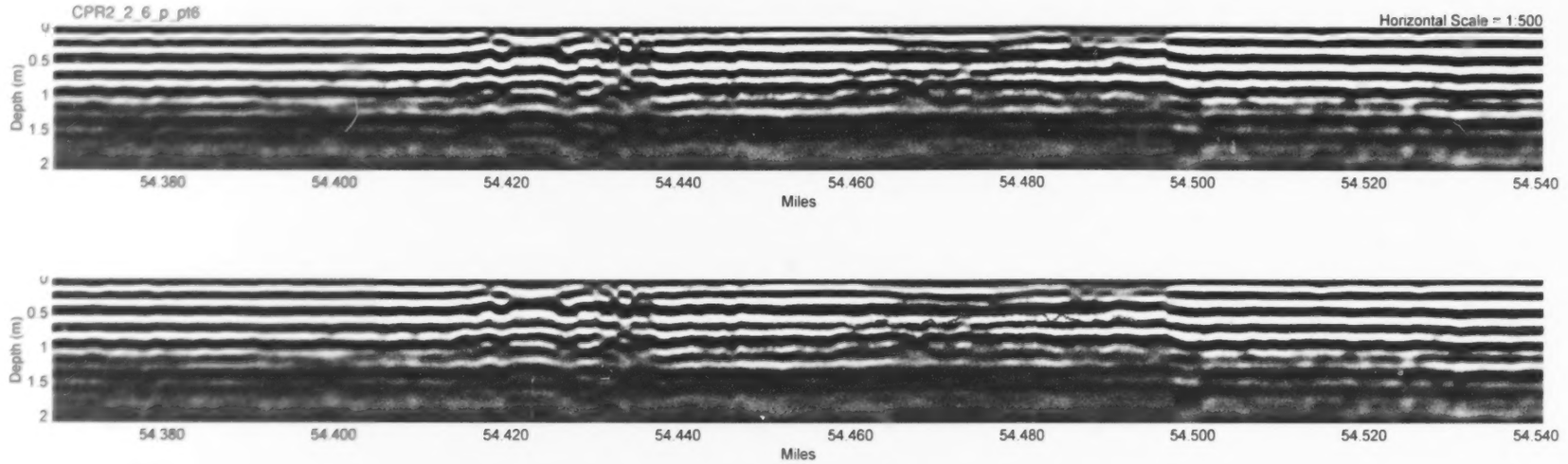
LEGEND

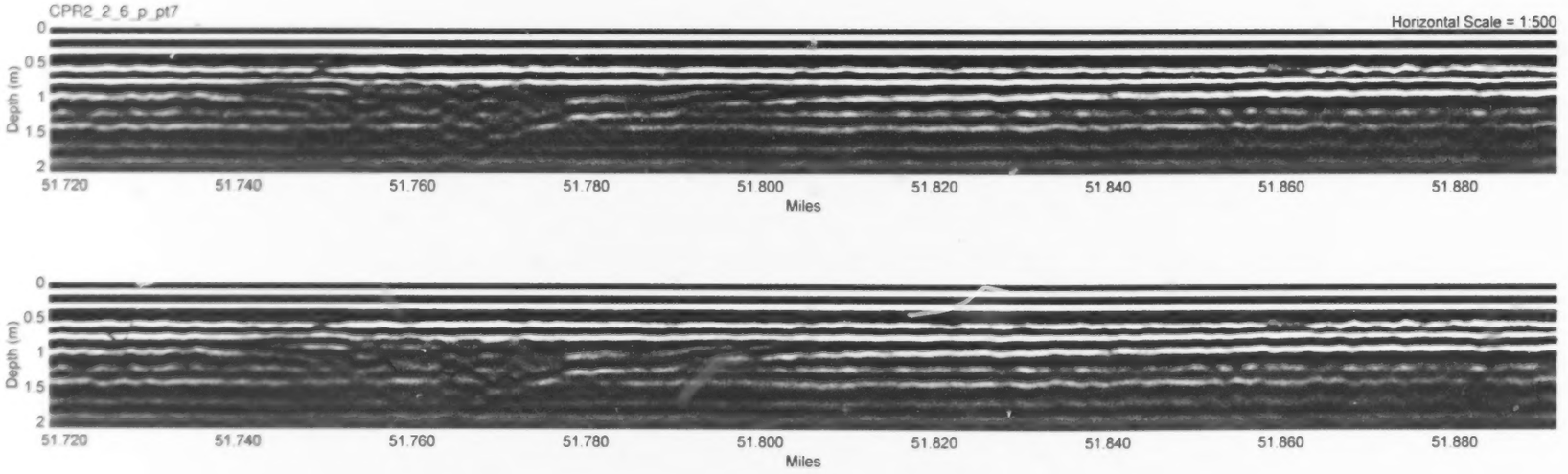
Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.

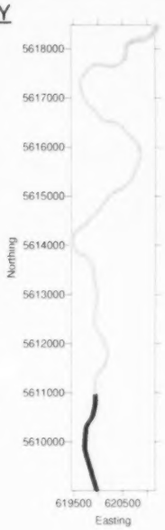
Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 27 CPR2_2_6c: 250 MHz GPR Data
Mile 54.36 to Mile 54.7





LOCATION OF SURVEY



Section of track imaged (approx.)
CPR Line #2
Other CPR line in survey

GPS coordinates NAD83 Zone 10

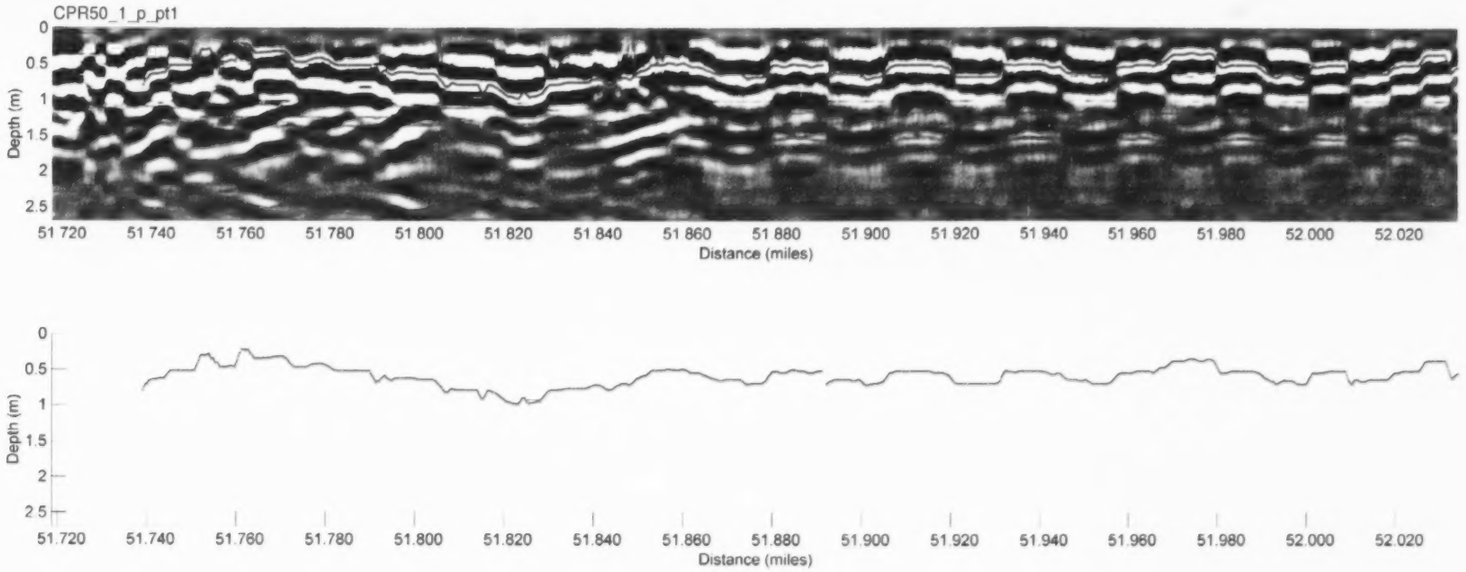
LEGEND

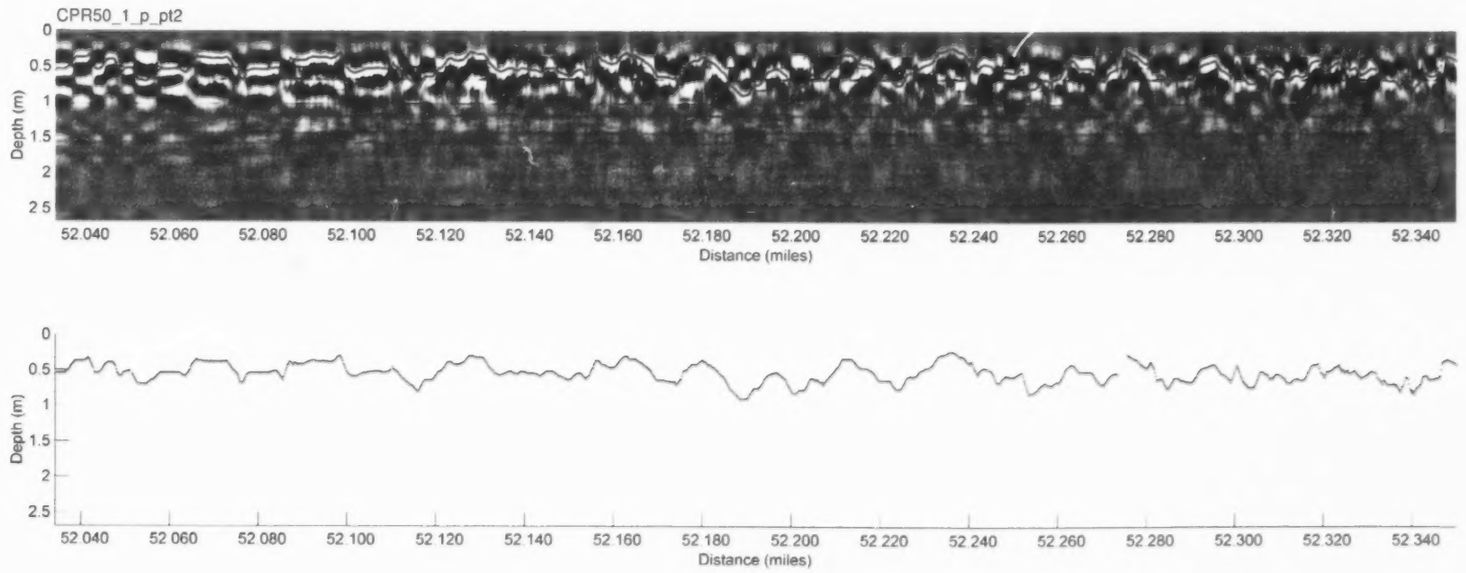
Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.

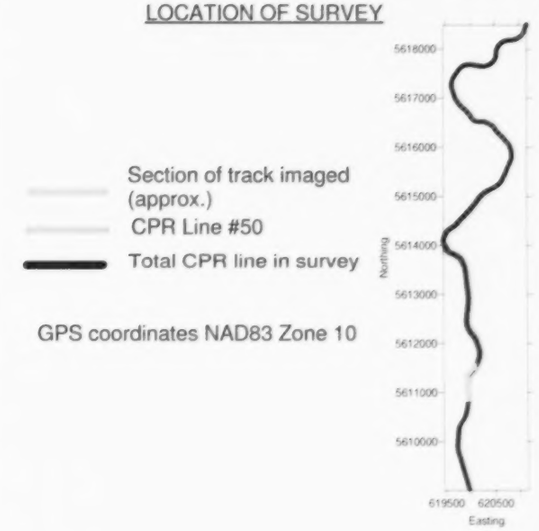
Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 28: CPR50_1a: 500 MHz GPR Data
Mile 51.72 to Mile 52.34





LOCATION OF SURVEY



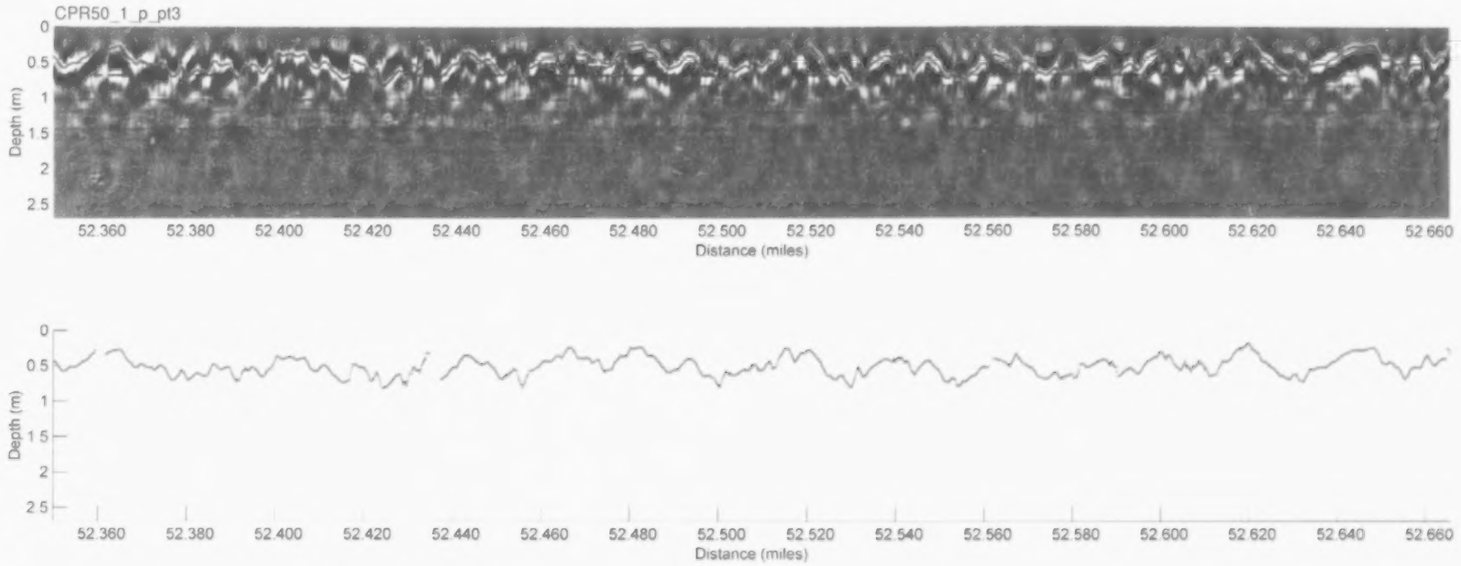
LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

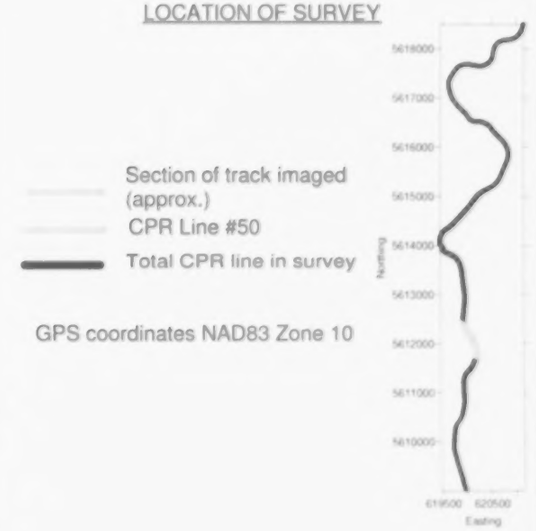
IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 29 CPR50_1b: 500 MHz GPR Data
Mile 52.36 to Mile 52.70



LOCATION OF SURVEY



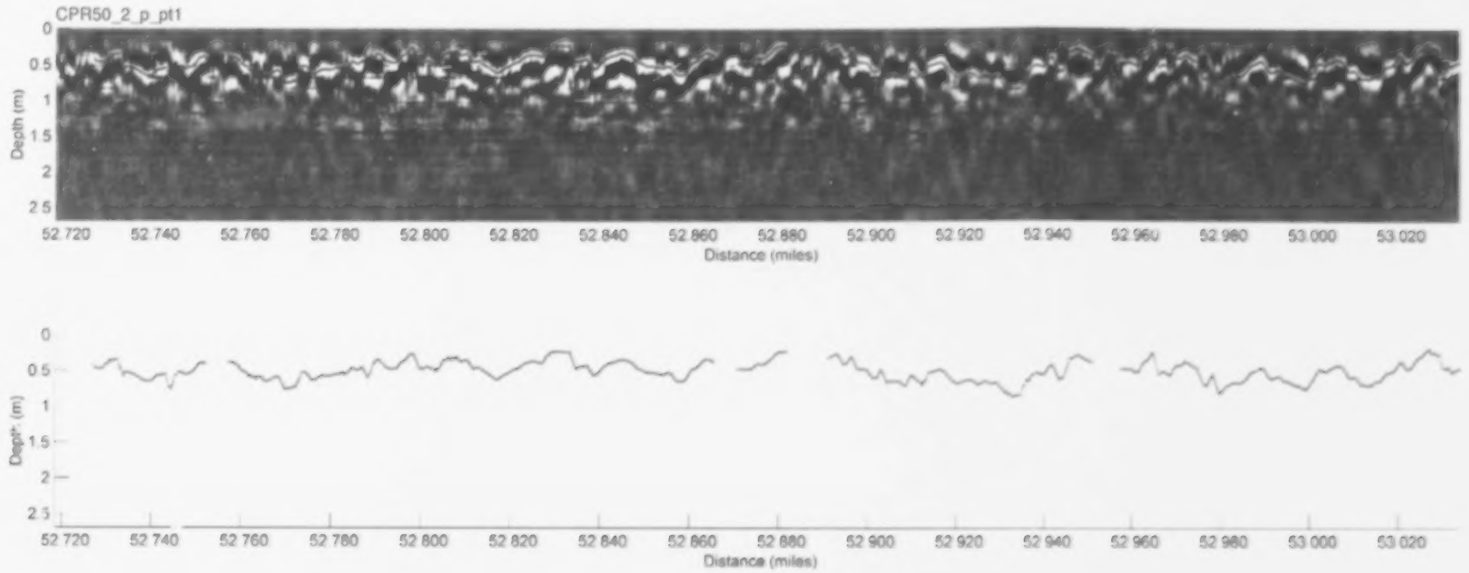
LEGEND

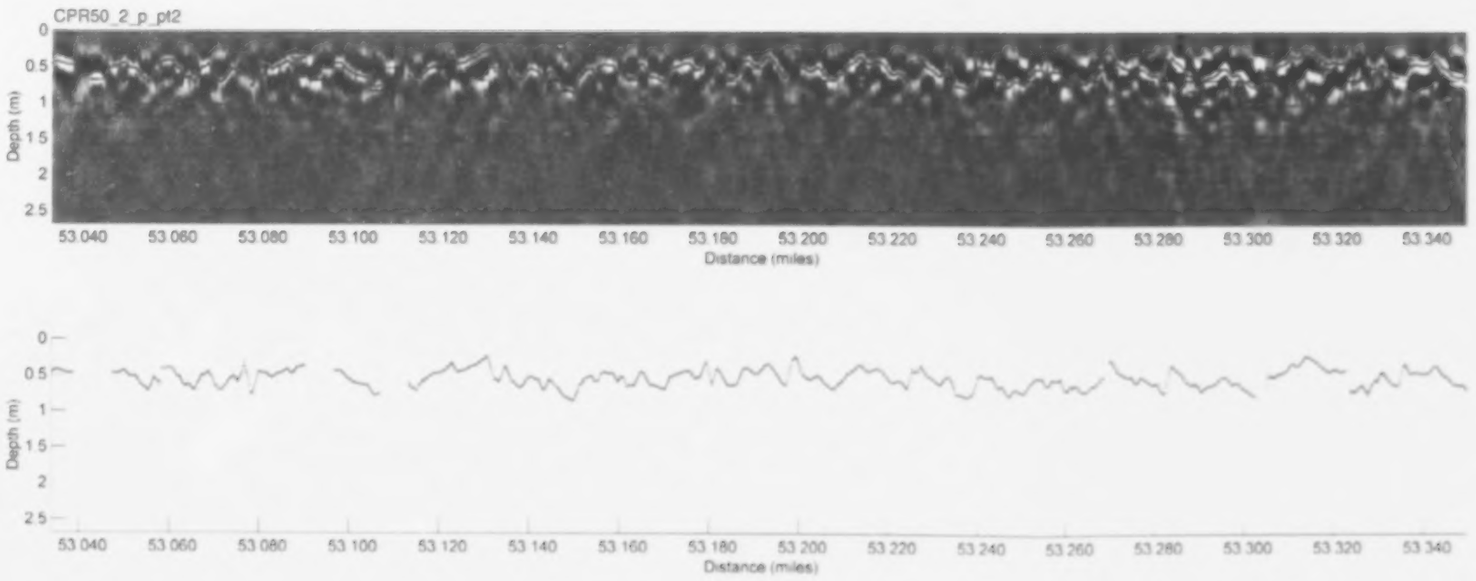
Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.

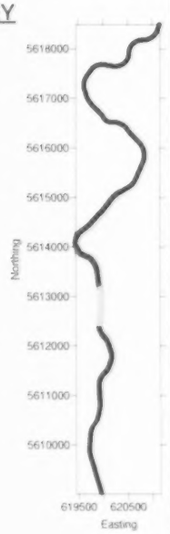
Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG.30: CPR50_2a: 500 MHz GPR Data
Mile 52.72 to Mile 53.40





LOCATION OF SURVEY



Section of track imaged (approx.)

CPR Line #50

Total CPR line in survey

GPS coordinates NAD83 Zone 10

LEGEND

interpreted base of ballast

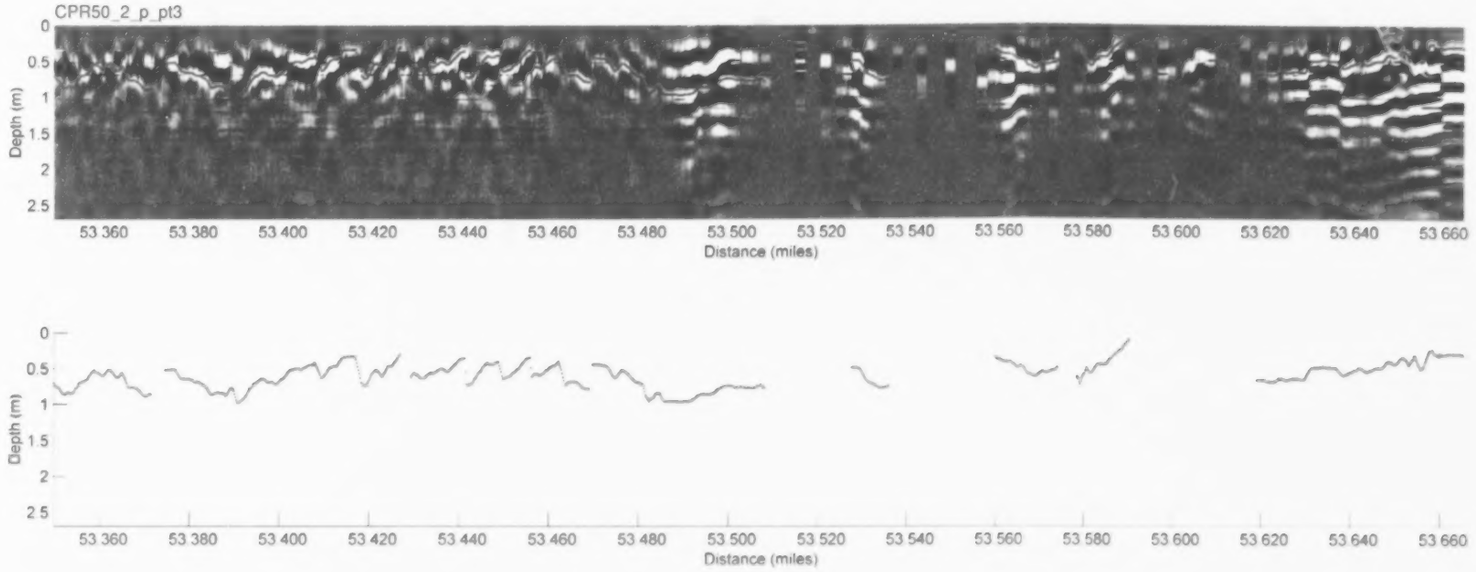
interpreted base of sub-ballast

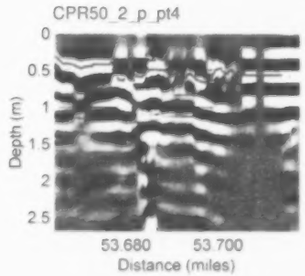
IMC

Associated Mining Consultants Ltd.

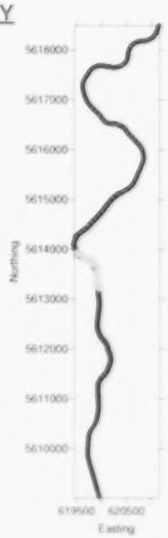
Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 31: CPR50_2b: 500 MHz GPR Data
Mile 53.36 to Mile 53.70





LOCATION OF SURVEY



Section of track imaged (approx.)
CPR Line #50
Total CPR line in survey

GPS coordinates NAD83 Zone 10

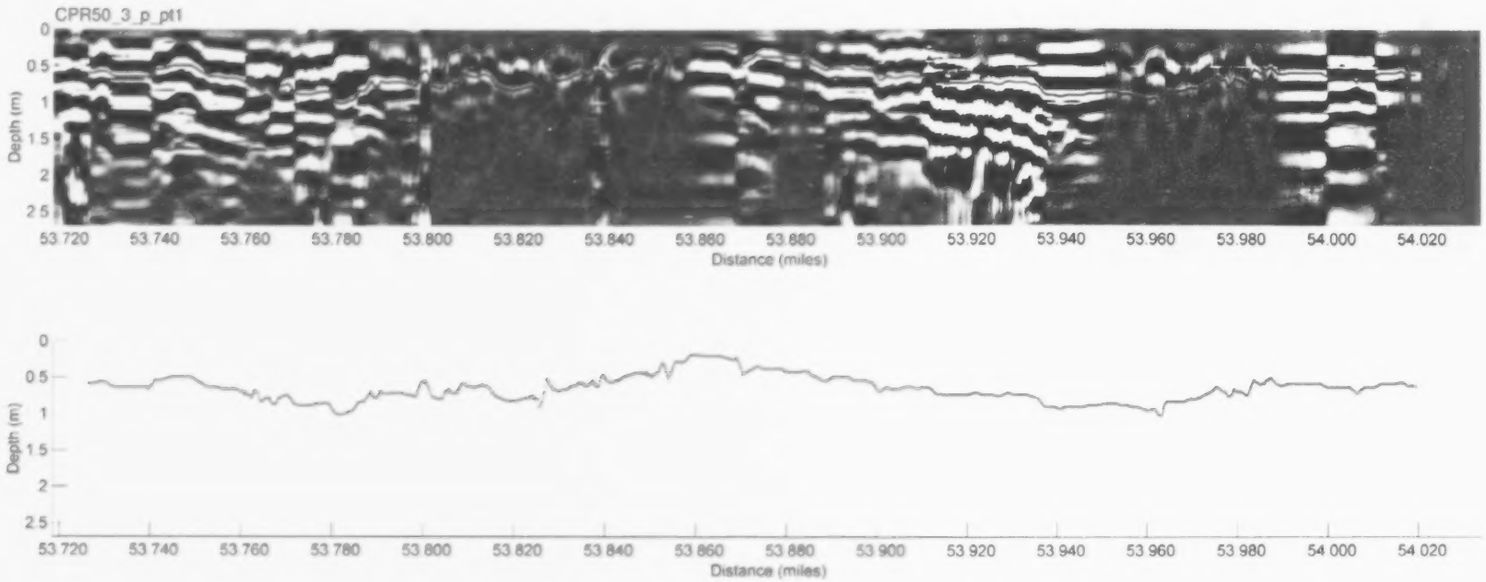
LEGEND

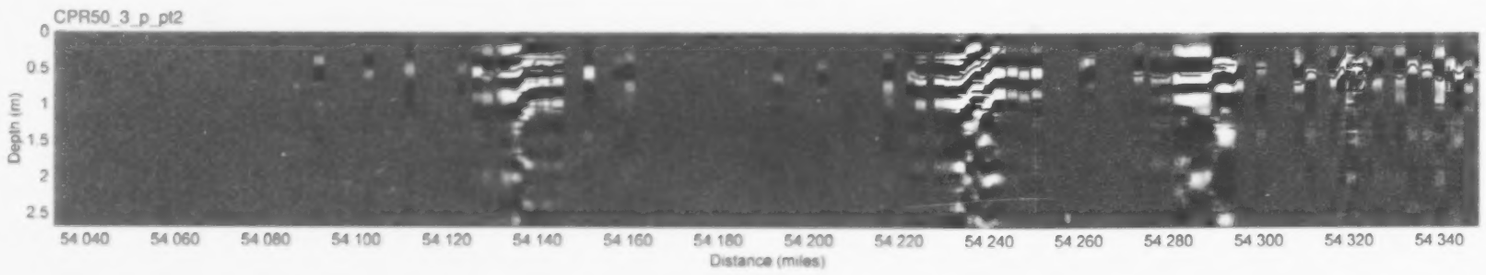
Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.

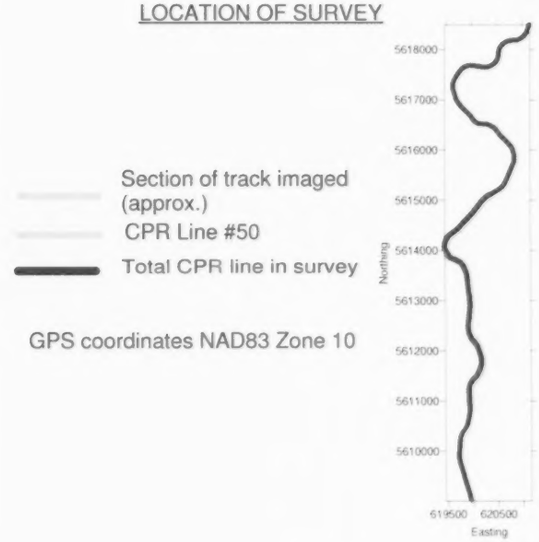
Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 32: CPR50_3a: 500 MHz GPR Data
Mile 53.70 to Mile 54.40





LOCATION OF SURVEY



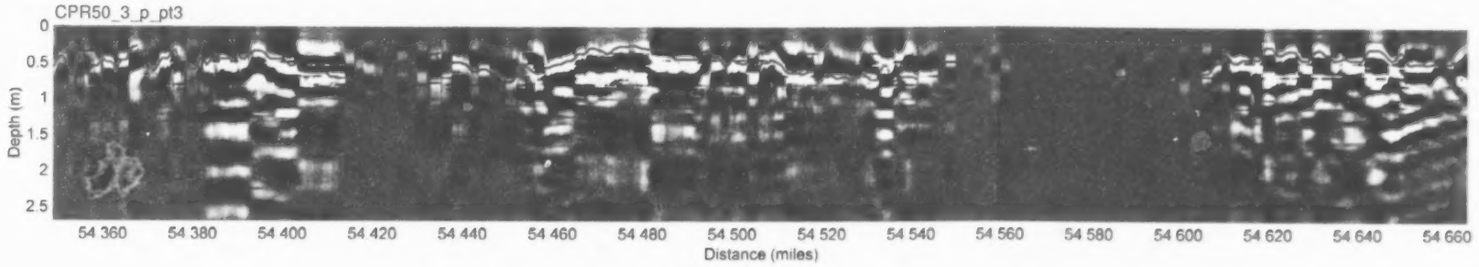
LEGEND

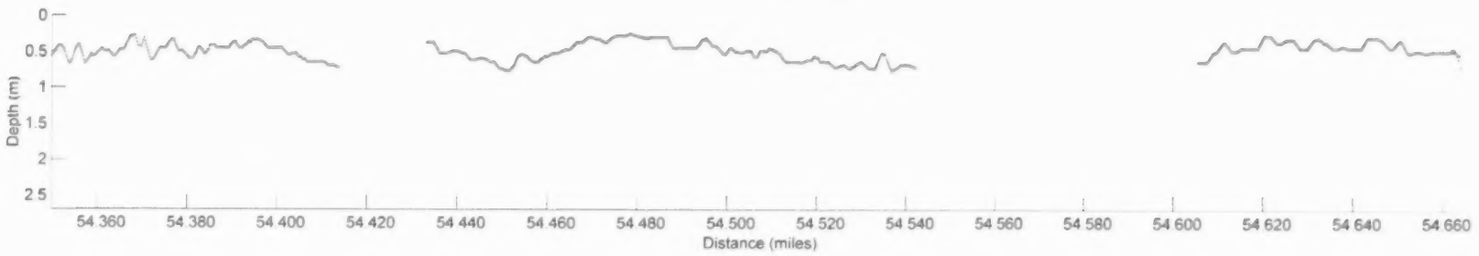
Interpreted base of ballast
Interpreted base of sub-ballast

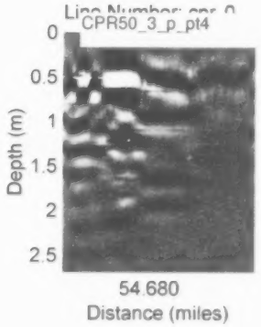
IMC
Associated Mining Consultants Ltd.

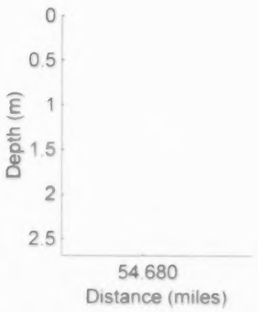
Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 33: CPR50_3b: 500 MHz GPR Data
Mile 54.36 to Mile 54.68

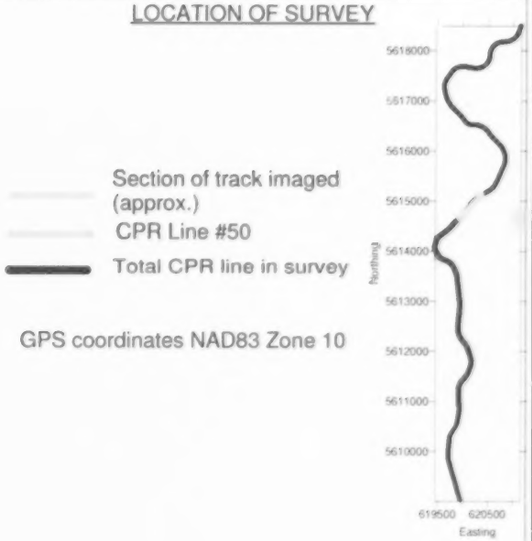








LOCATION OF SURVEY



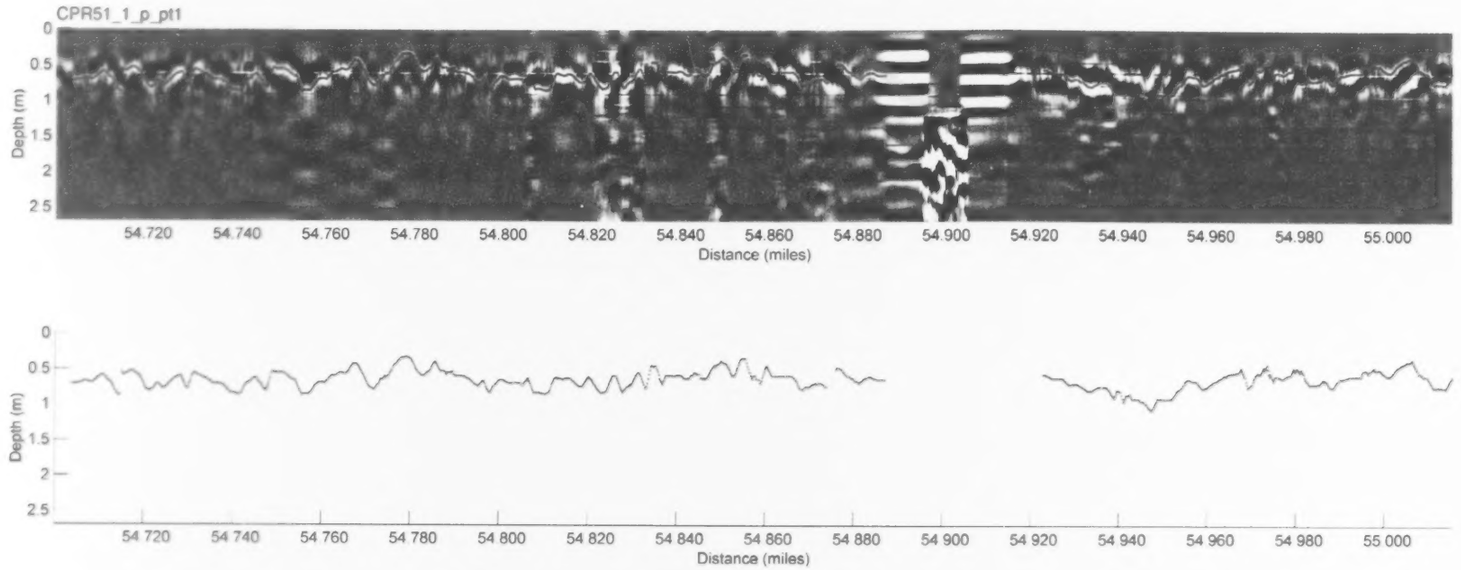
LEGEND

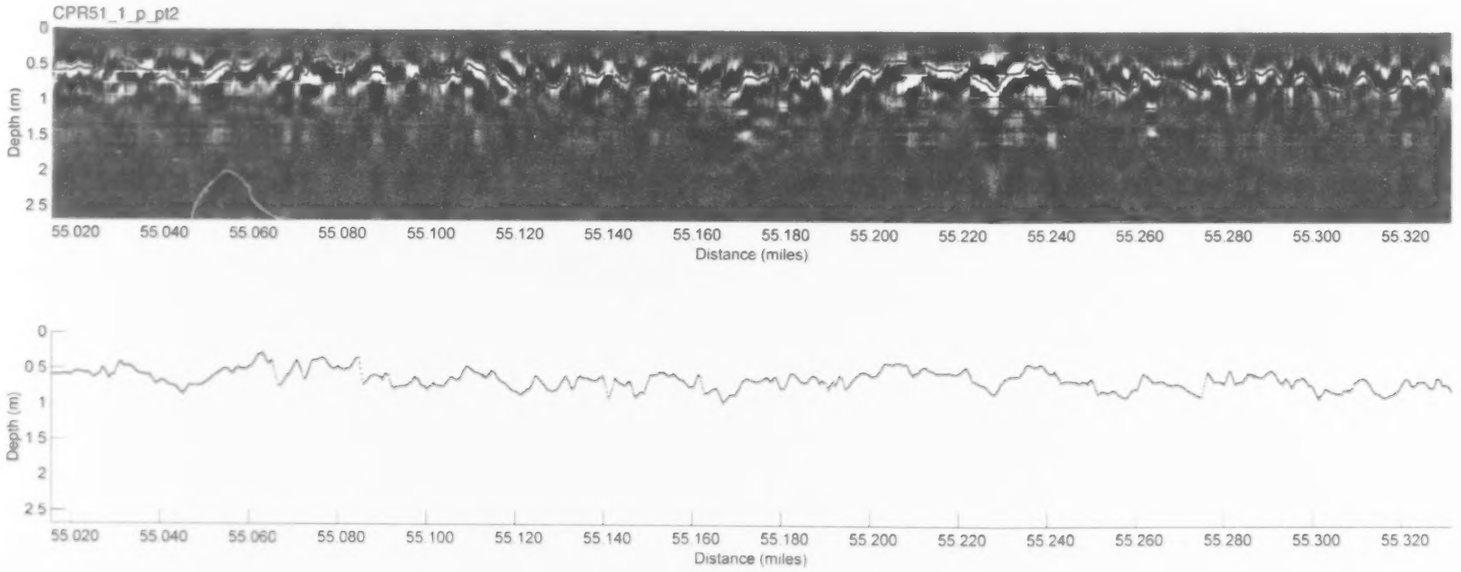
Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.

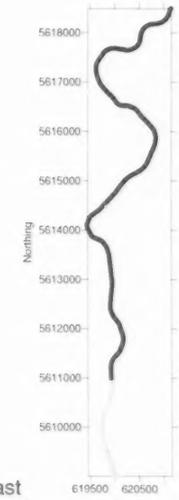
Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 34: CPR51_1a: 500 MHz GPR Data
Mile 54.68 to Mile 55.32





LOCATION OF SURVEY



Section of track imaged (approx.)

CPR Line #51

Other CPR line in survey

GPS coordinates NAD83 Zone 10

LEGEND

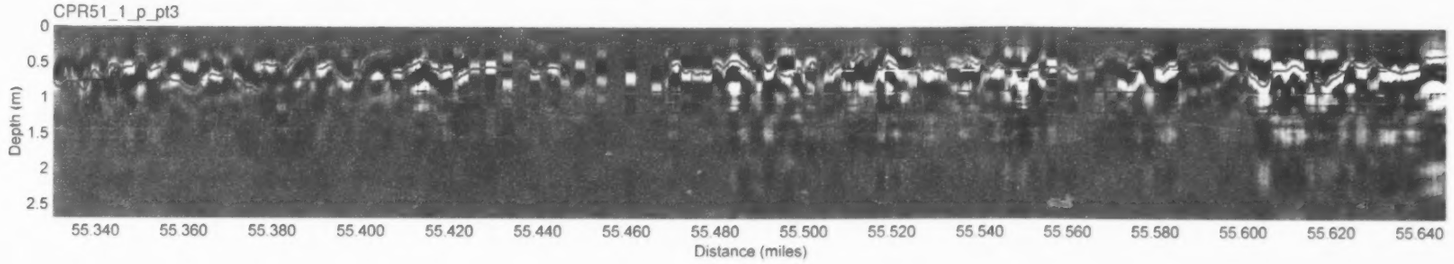
Interpreted base of ballast

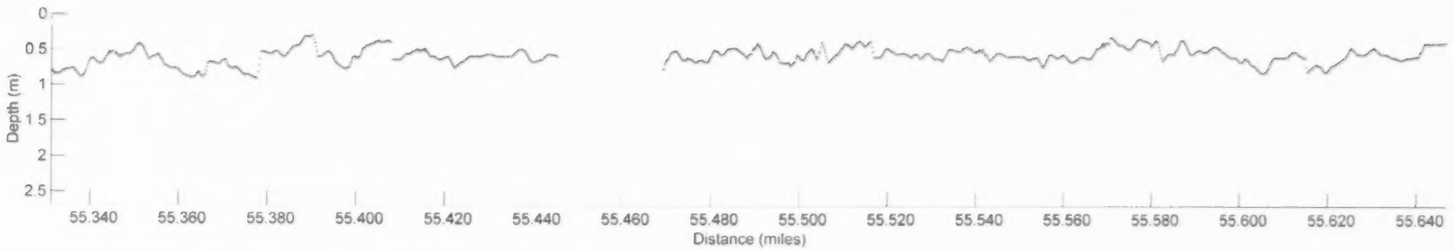
Interpreted base of sub-ballast

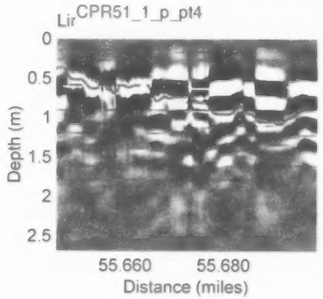
IMC
Associated Mining Consultants Ltd.

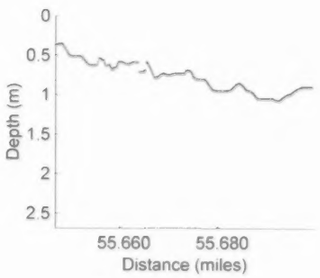
Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 35: CPR51_1b: 500 MHz GPR Data
Mile 55.34 to Mile 55.68









LOCATION OF SURVEY

Section of track imaged (approx.)

CPR Line #51

Other CPR line in survey

GPS coordinates NAD83 Zone 10

LEGEND

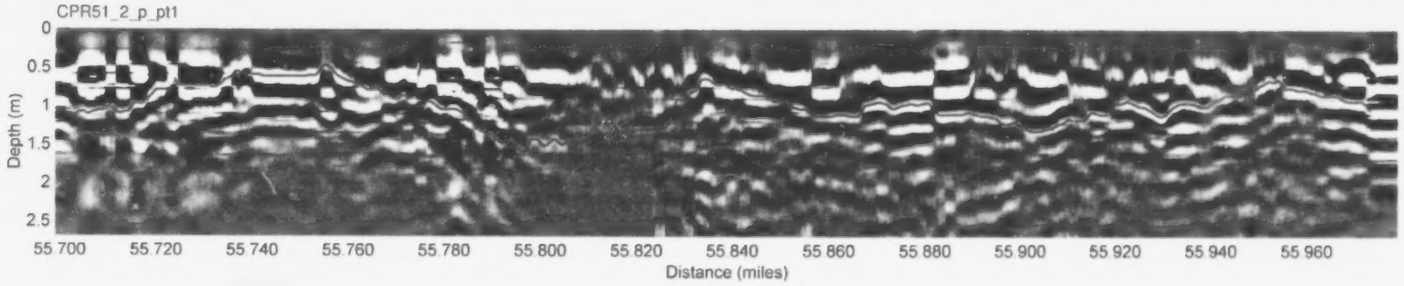
Interpreted base of ballast

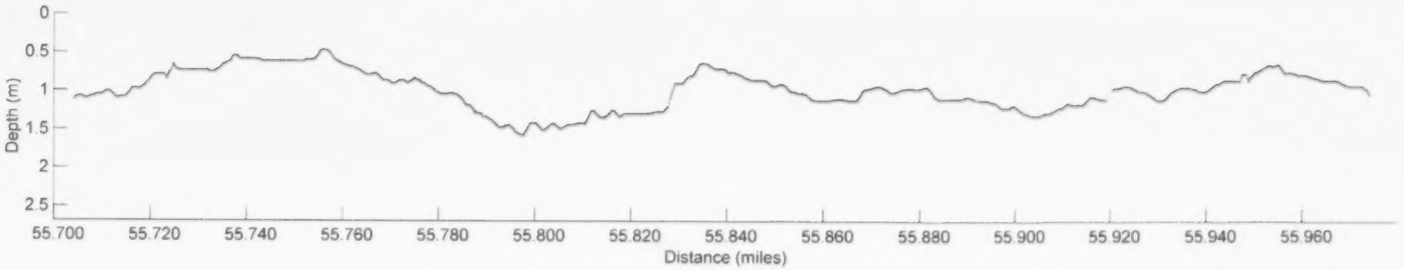
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 36: CPR51_2: 500 MHz GPR Data
Mile 55.70 to Mile 55.96





LOCATION OF SURVEY

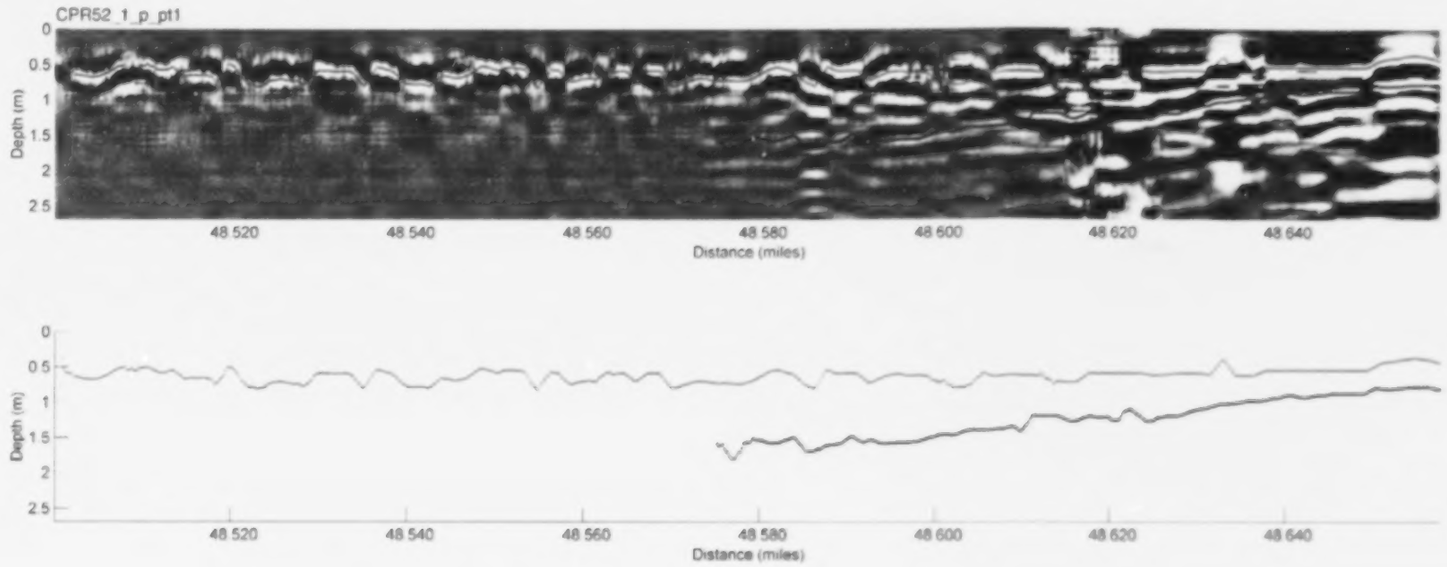
Section of track imaged (approx.)
CPR Line #51
Other CPR line in survey

GPS coordinates NAD83 Zone 10

LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.



Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 37: CPR52_1a: 500 MHz GPR Data Mile 48.52 to Mile 48.8

LOCATION OF SURVEY

Section of track imaged (approx.)
CPR Line #52
Other CPR line in survey

GPS coordinates NAD83 Zone 10

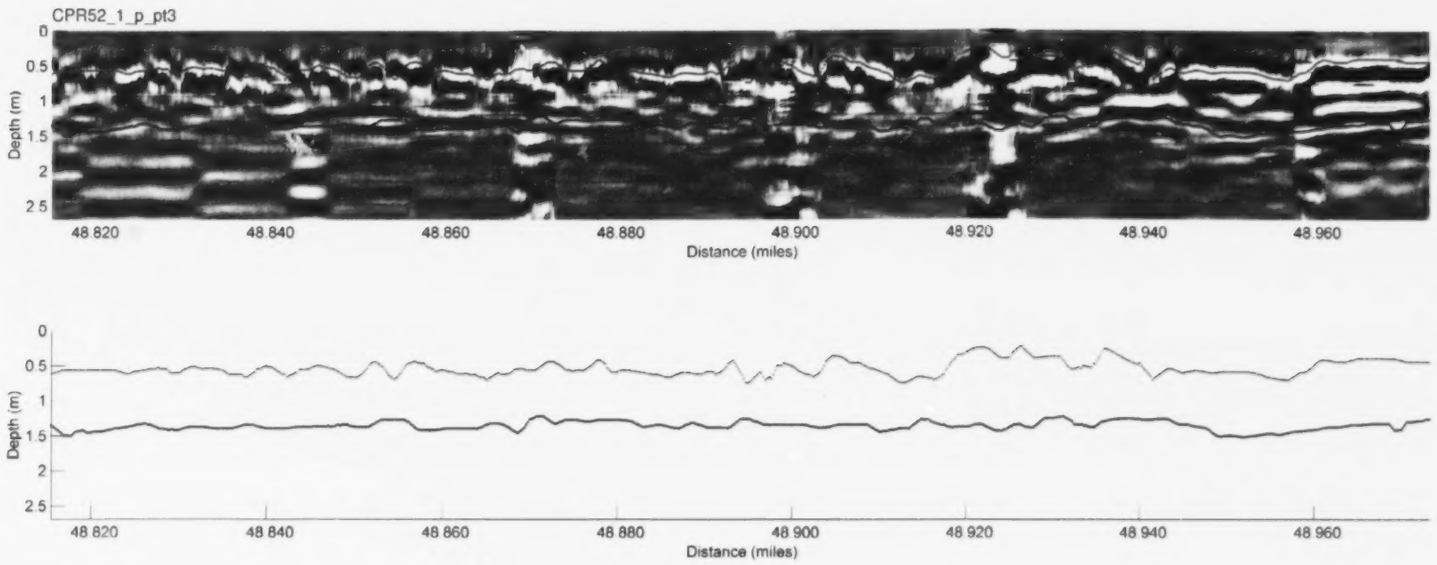
LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

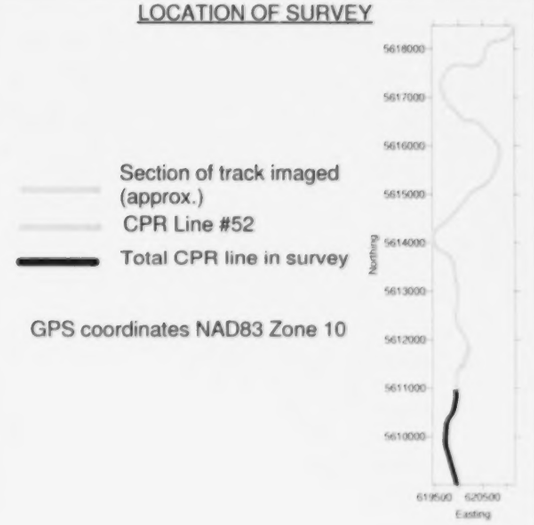
IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 38: CPR52_1b: 500 MHz GPR Data
Mile 48.82 to Mile 49.12



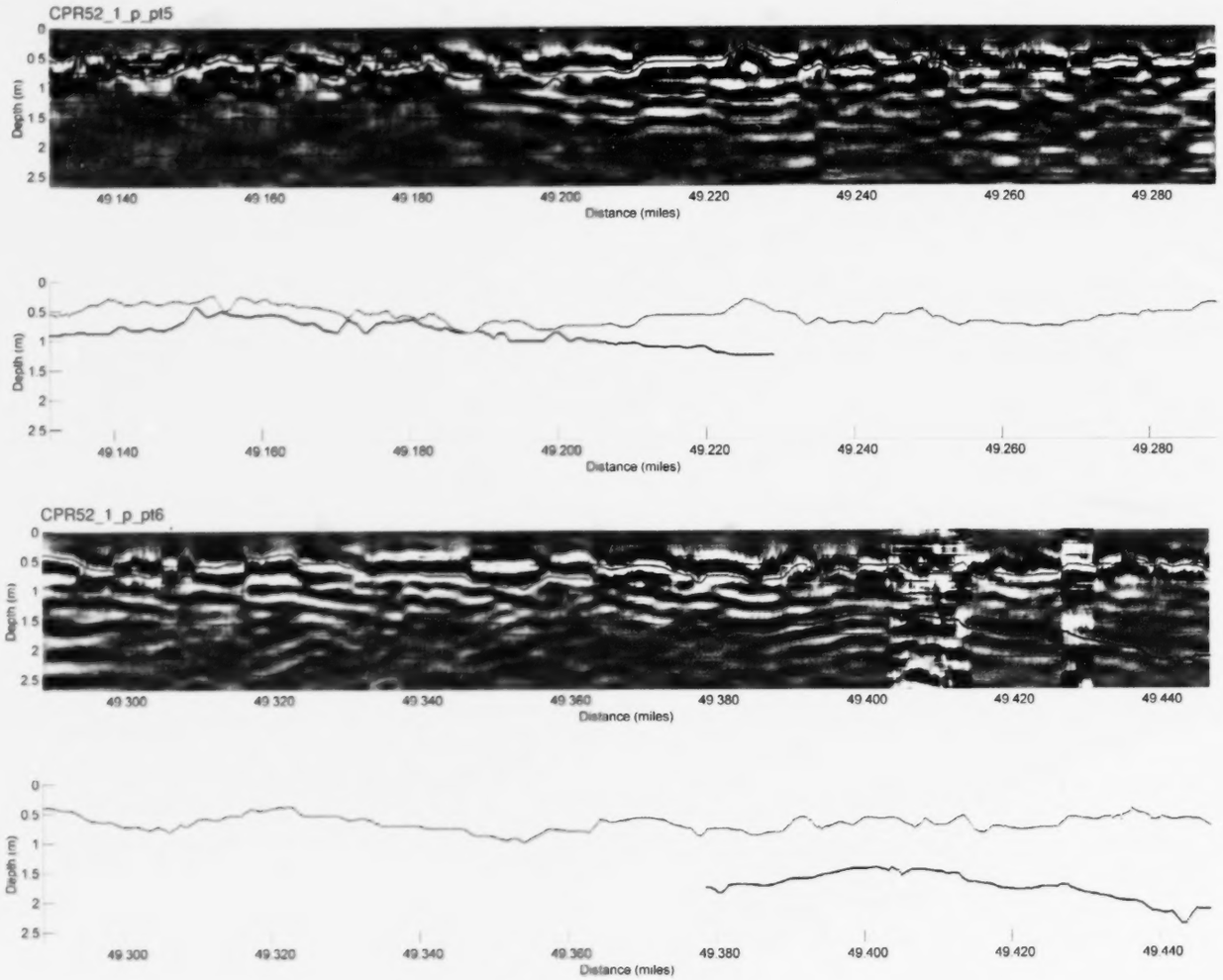
LOCATION OF SURVEY



LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

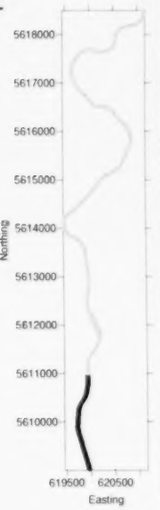
IMC
Associated Mining Consultants Ltd.



Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 39: CPR52_1c: 500 MHz GPR Data
Mile 49.14 to Mile 49.50

LOCATION OF SURVEY



Section of track imaged (approx.)
CPR Line #52
Other CPR lines in survey

GPS coordinates NAD83 Zone 10

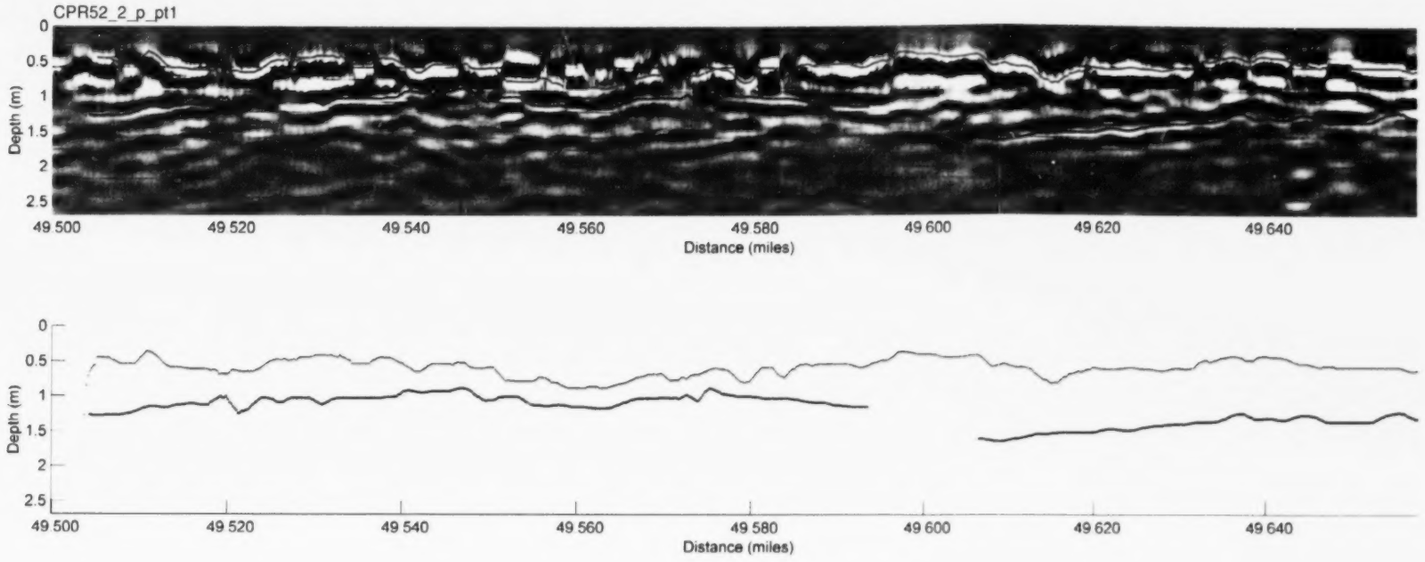
LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

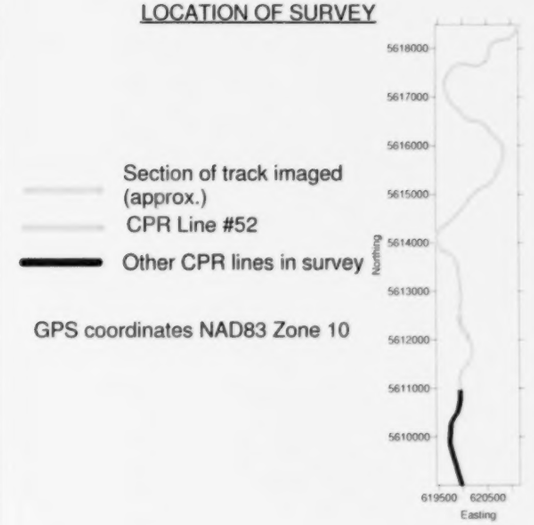
IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 40: CPR52_2a: 500 MHz GPR Data
Mile 49.50 to Mile 50.0



LOCATION OF SURVEY



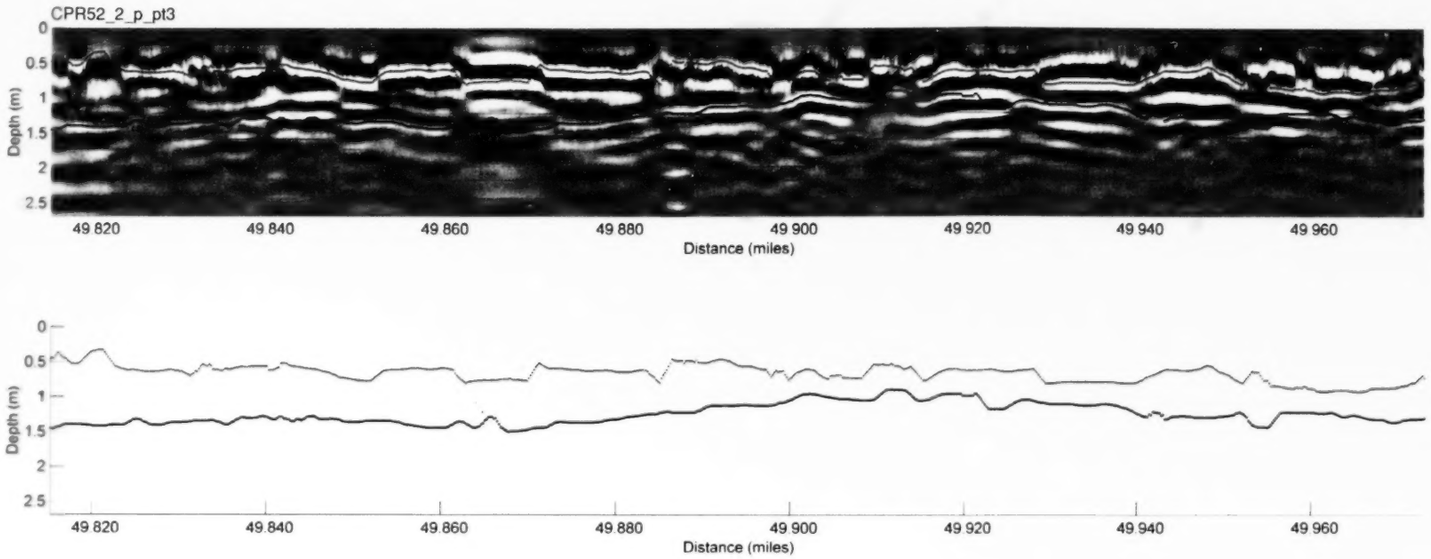
LEGEND

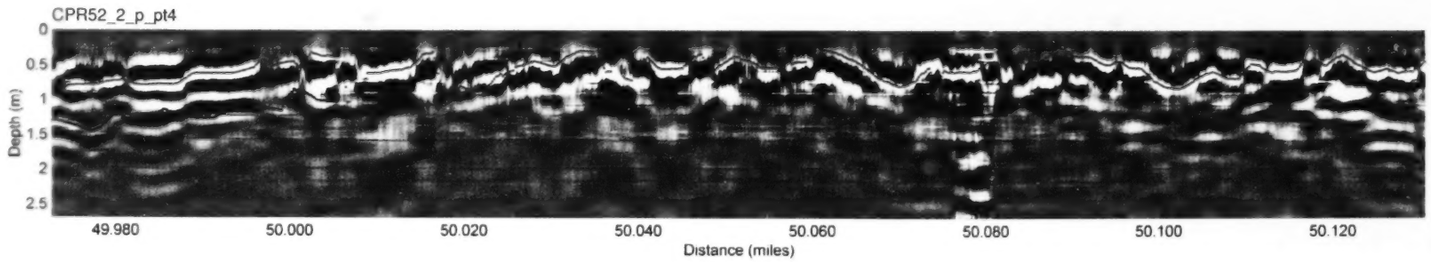
Interpreted base of ballast
Interpreted base of sub-ballast

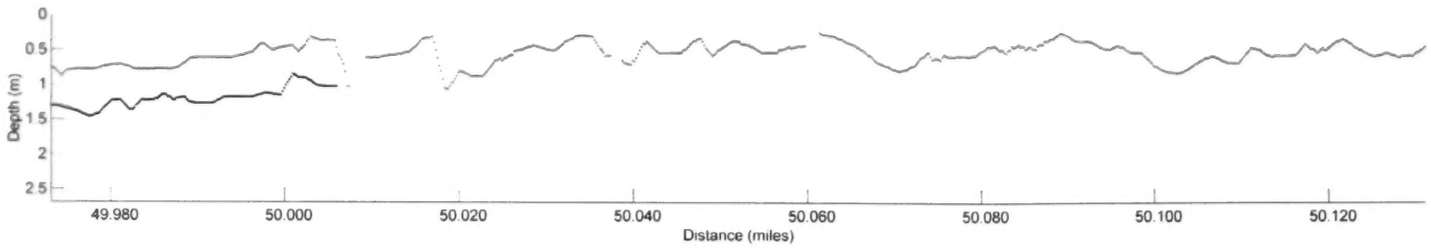
IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

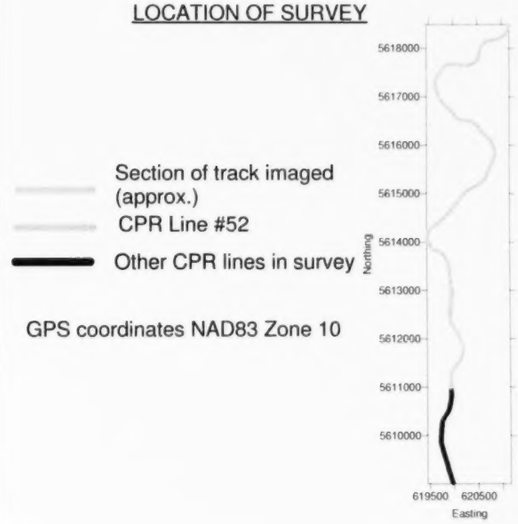
FIG. 41: CPR52_2b: 500 MHz GPR Data
Mile 49.82 to Mile 50.12







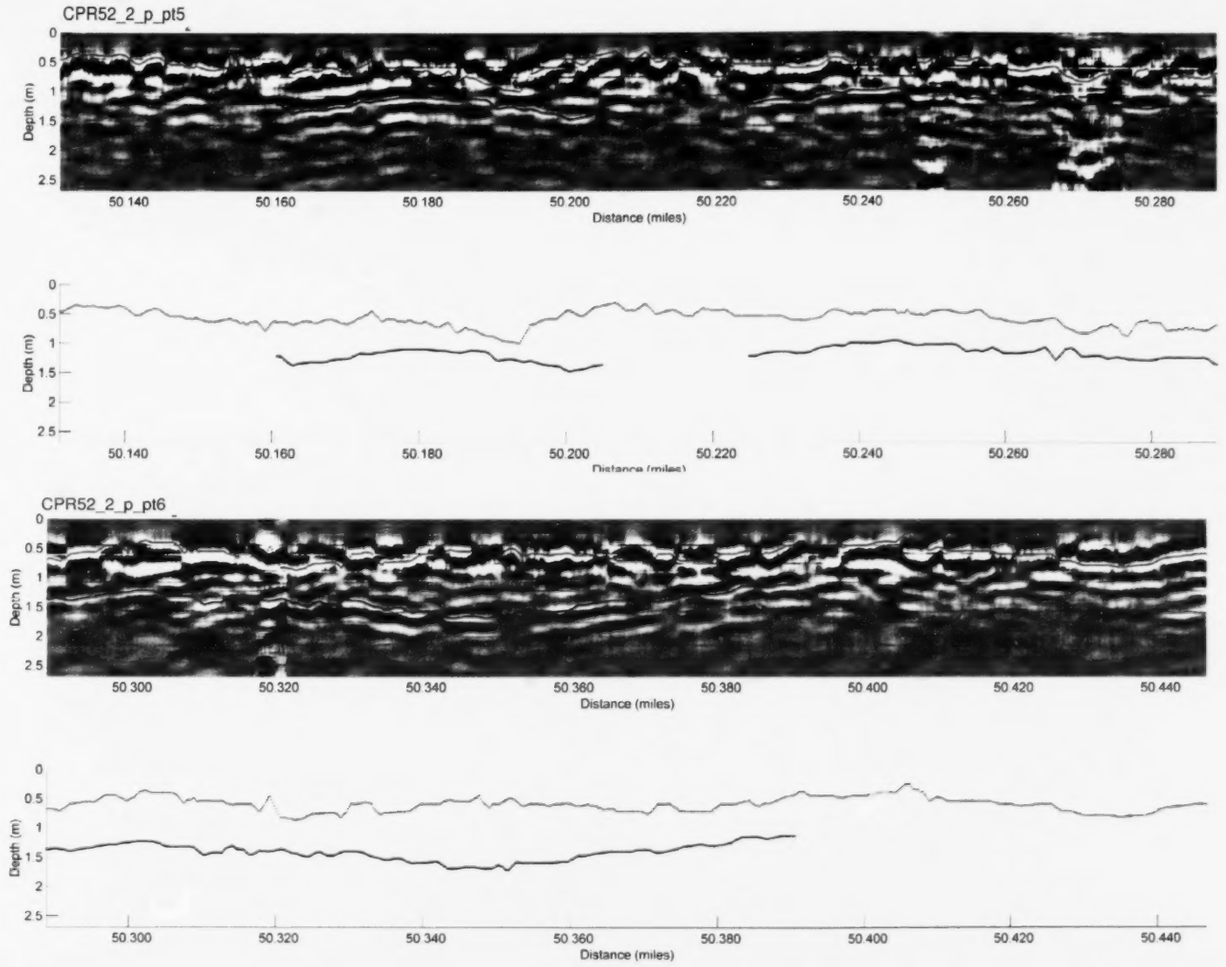
LOCATION OF SURVEY



LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

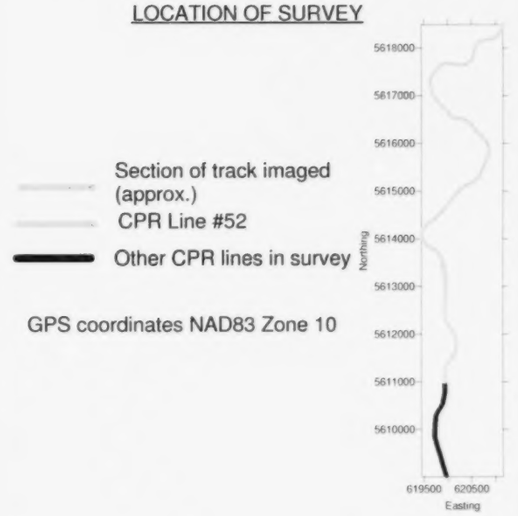
IMC
Associated Mining Consultants Ltd.



Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 42: CPR52_2c: 500 MHz GPR Data
Mile 50.14 to Mile 50.50

LOCATION OF SURVEY



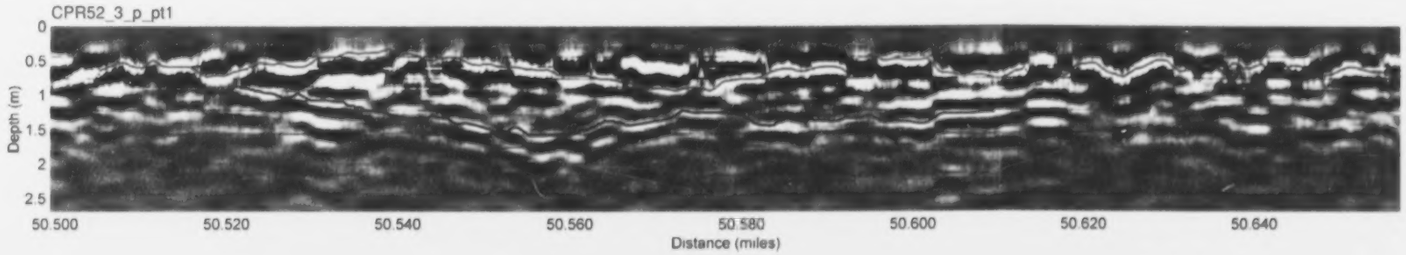
LEGEND

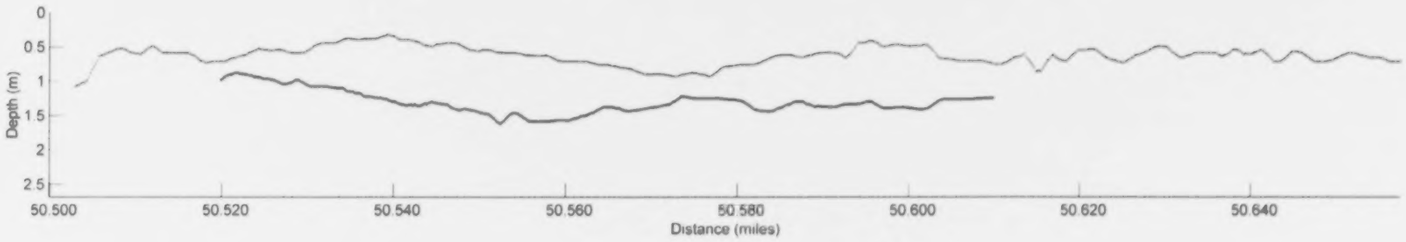
Interpreted base of ballast
Interpreted base of sub-ballast

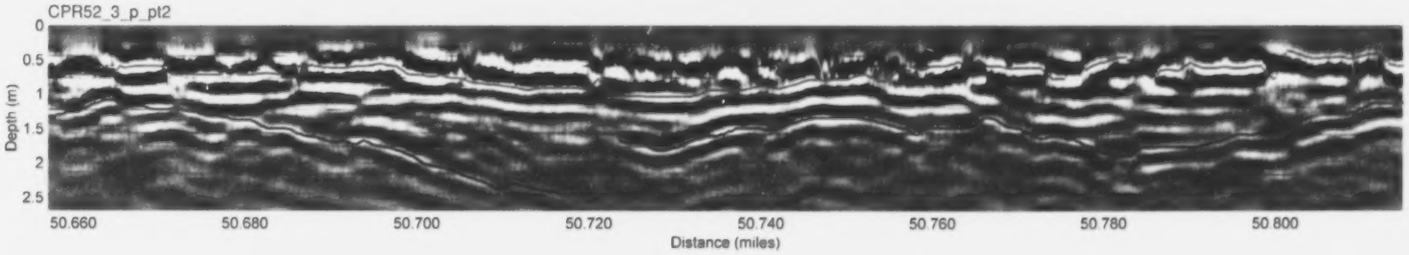
IMC
Associated Mining Consultants Ltd.

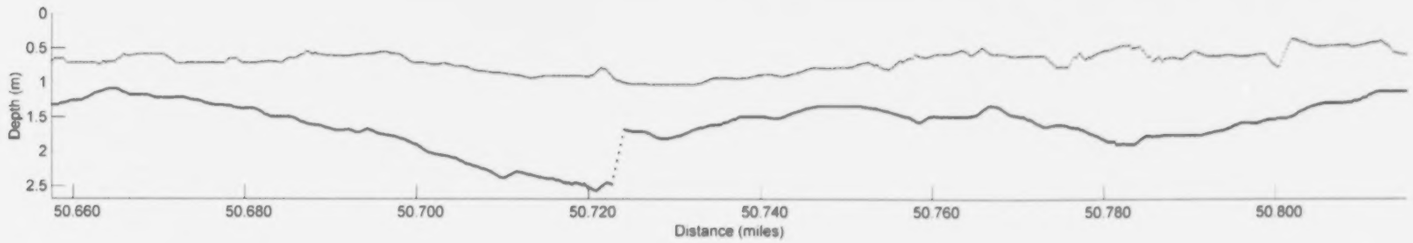
Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 43: CPR52_3a: 500 MHz GPR Data
Mile 50.50 to Mile 50.80

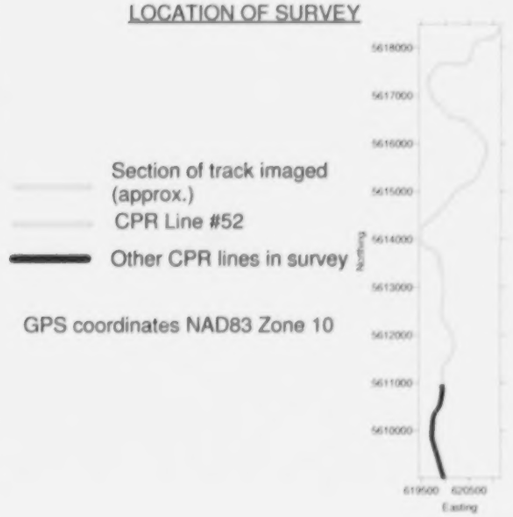








LOCATION OF SURVEY



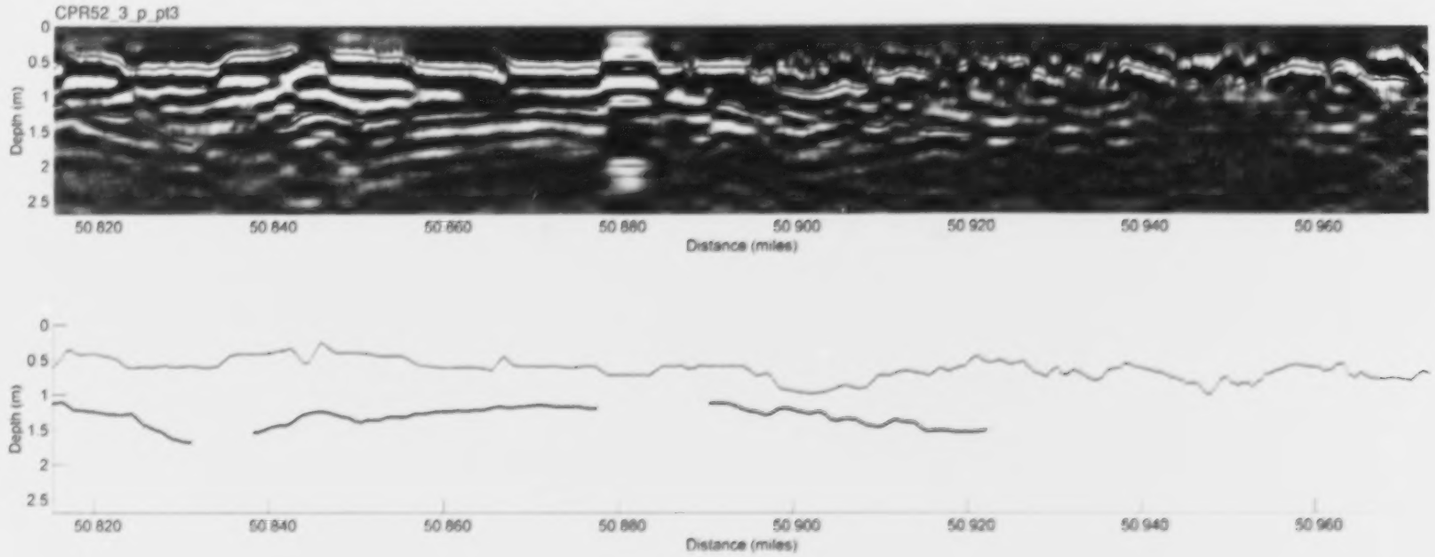
LEGEND

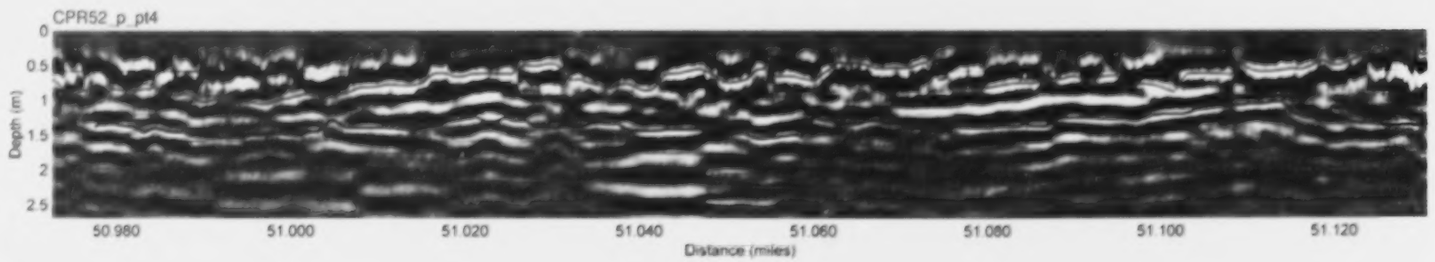
Interpreted base of ballast
Interpreted base of sub-ballast

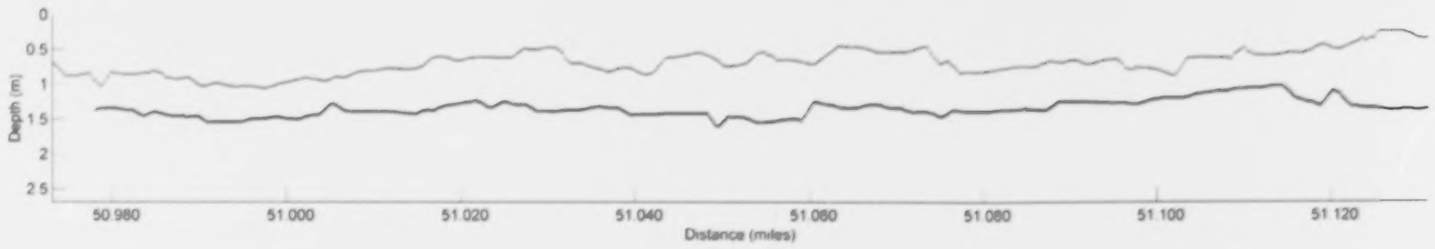
IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

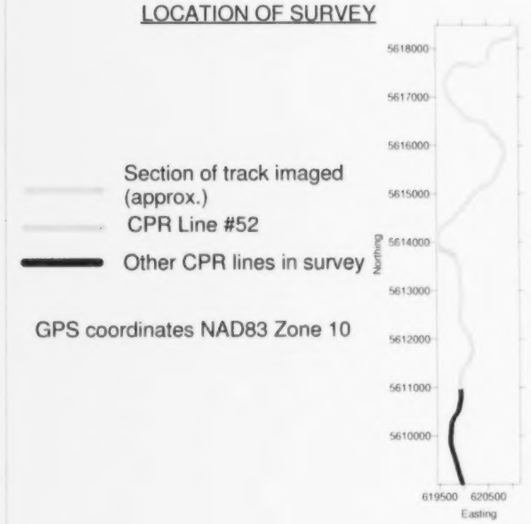
FIG. 44: CPR52_3b: 500 MHz GPR Data
Mile 50.80 to Mile 51.12







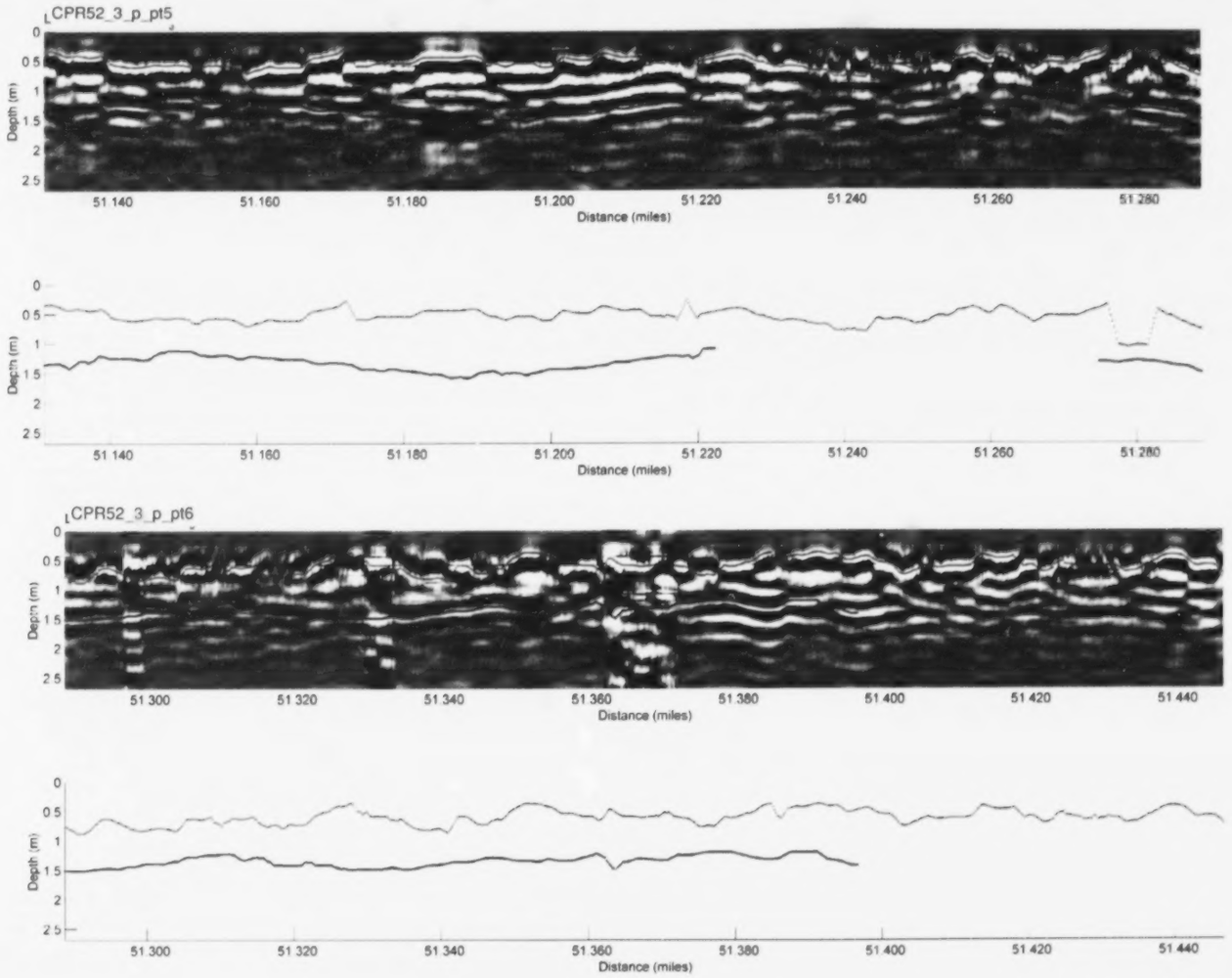
LOCATION OF SURVEY



LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

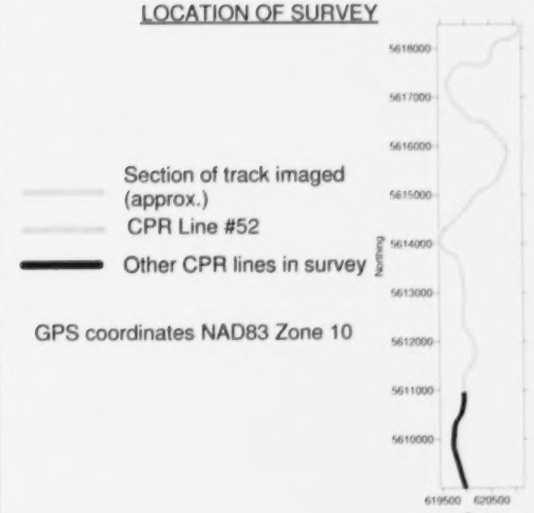
IMC
Associated Mining Consultants Ltd.



Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 45: CPR52_3c: 500 MHz GPR Data
Mile 51.12 to Mile 51.50

LOCATION OF SURVEY



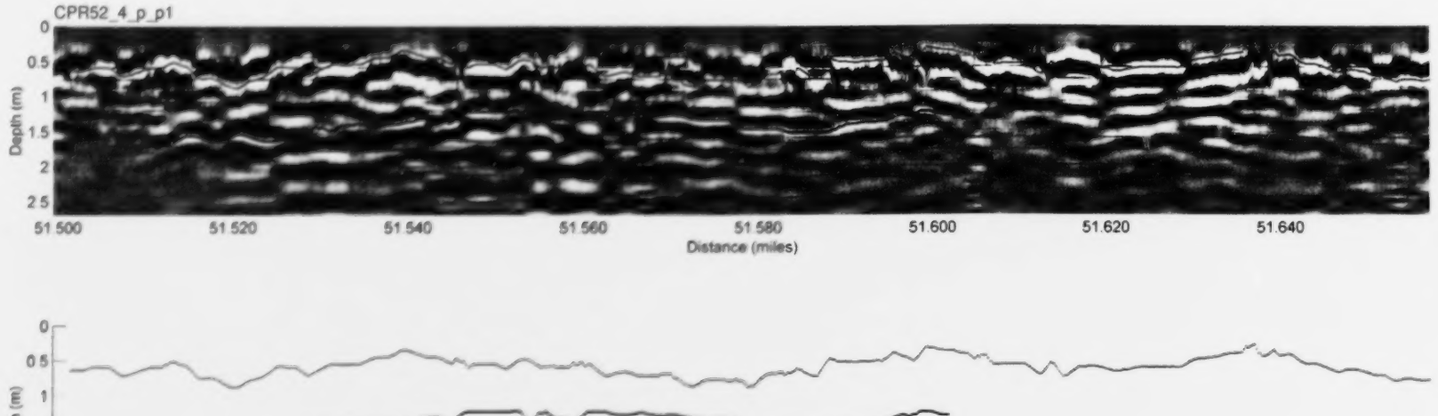
LEGEND

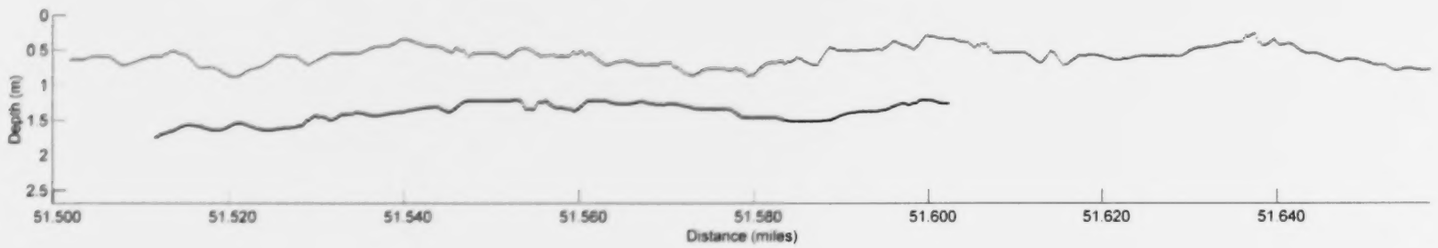
Interpreted base of ballast
Interpreted base of sub-ballast

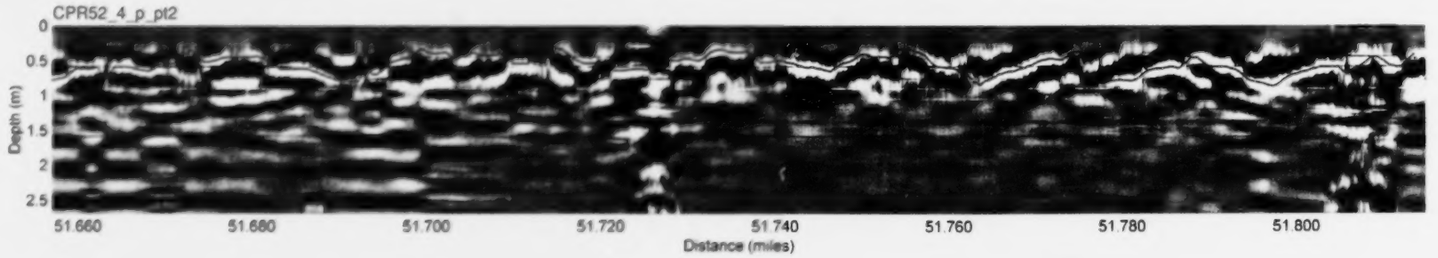
IMC
Associated Mining Consultants Ltd.

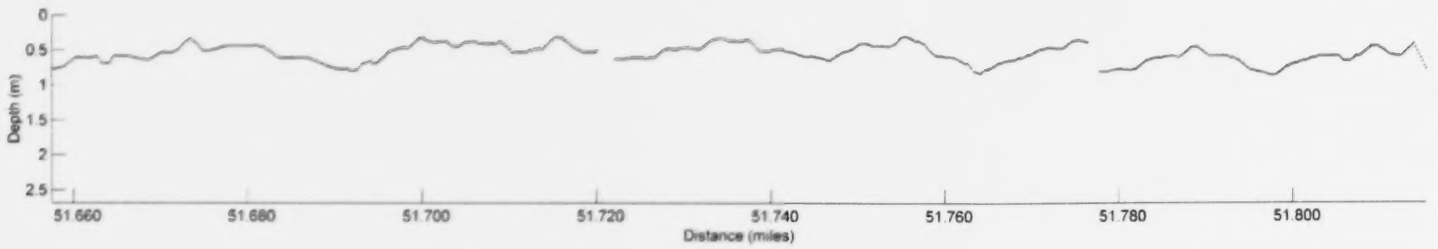
Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 46: CPR52_4a: 500 MHz GPR Data
Mile 52.50 to Mile 51.82

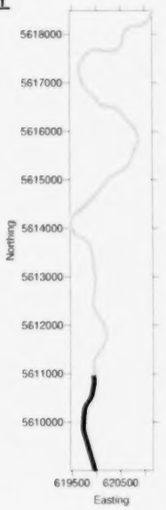








LOCATION OF SURVEY



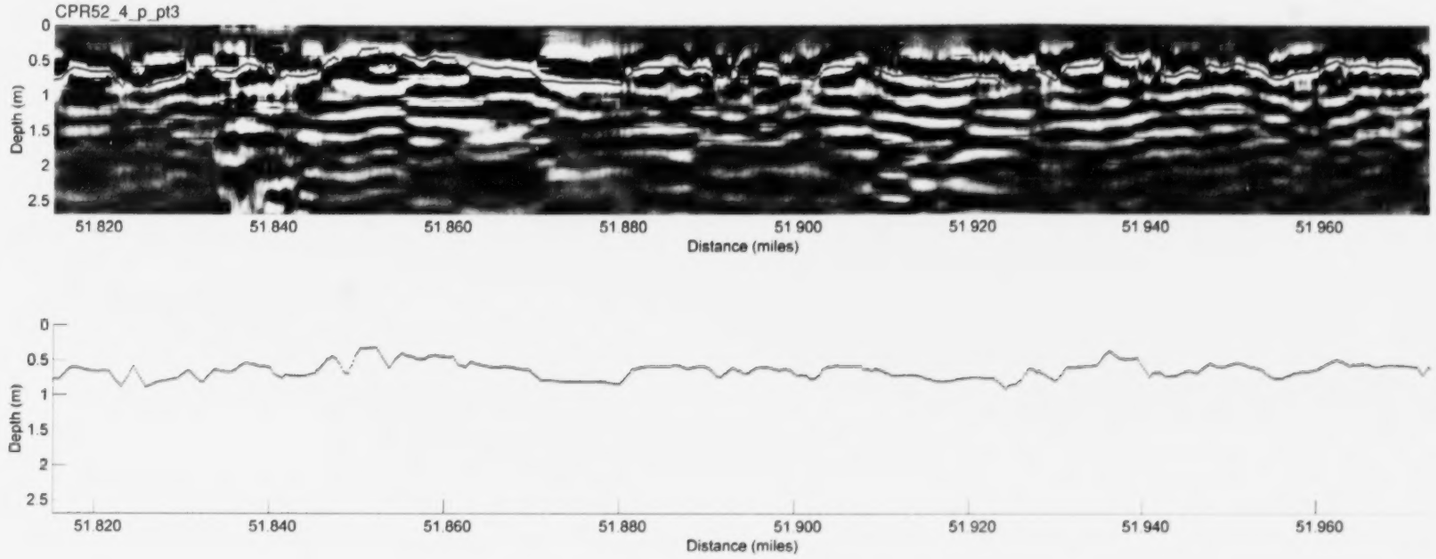
Section of track imaged (approx.)
CPR Line #52
Other CPR lines in survey

GPS coordinates NAD83 Zone 10

LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

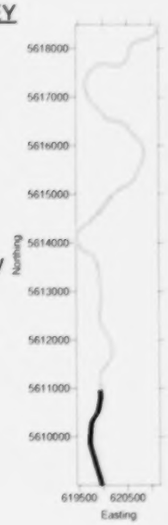
IMC
Associated Mining Consultants Ltd.



Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 47: CPR52_4b: 500 MHz GPR Data
Mile 51.82 to Mile 52.14

LOCATION OF SURVEY



Section of track imaged (approx.)
CPR Line #52
Other CPR lines in survey

GPS coordinates NAD83 Zone 10

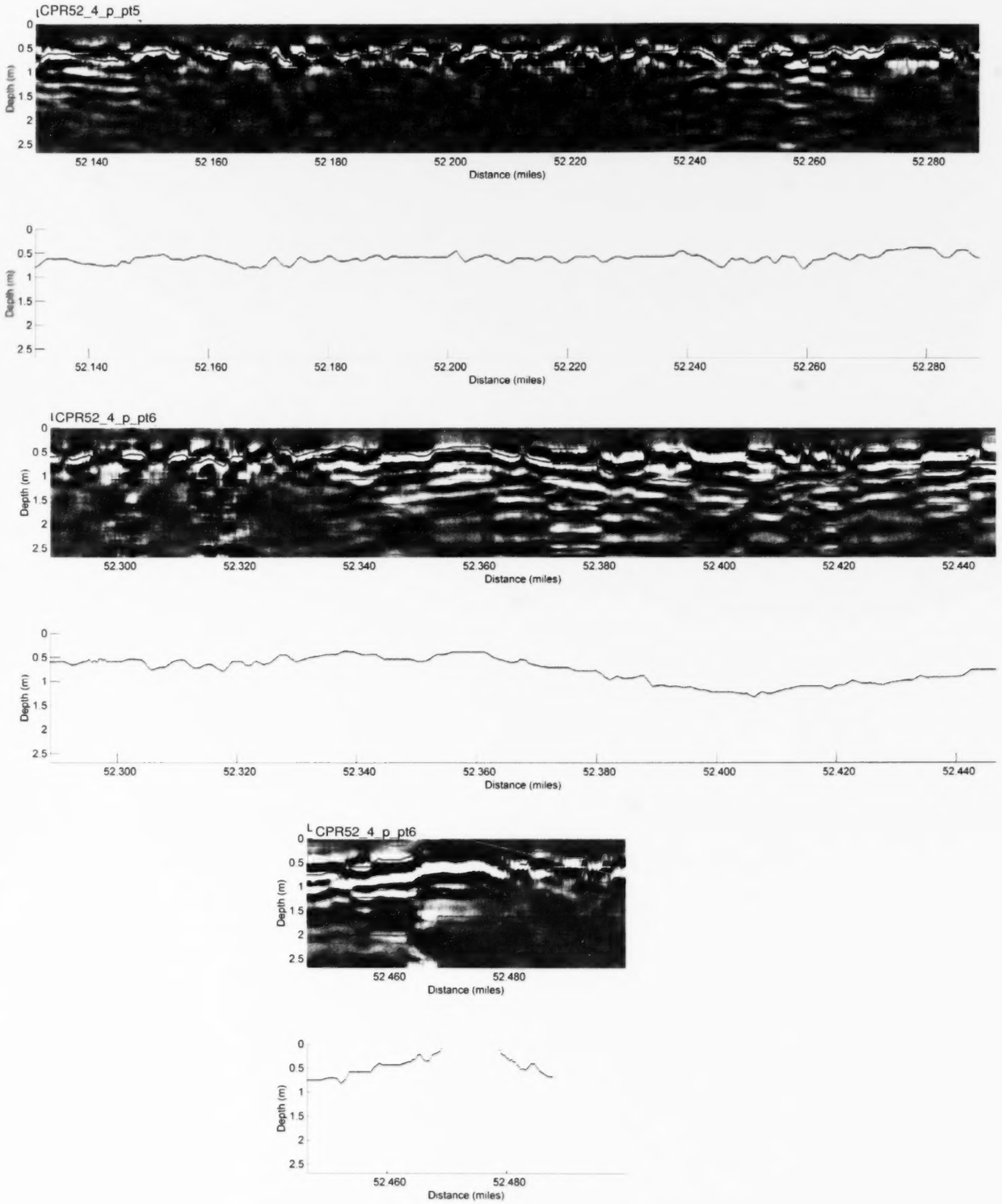
LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

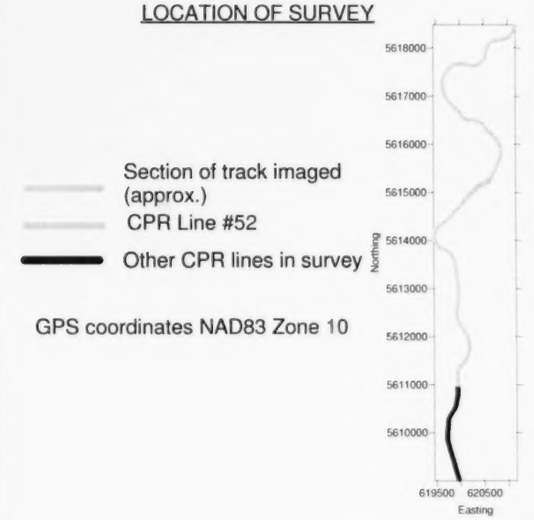
IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CPR Rail line, Ashcroft, B.C.

FIG. 48: CPR52_4c: 500 MHz GPR Data
Mile 52.13 to Mile 52.44



LOCATION OF SURVEY



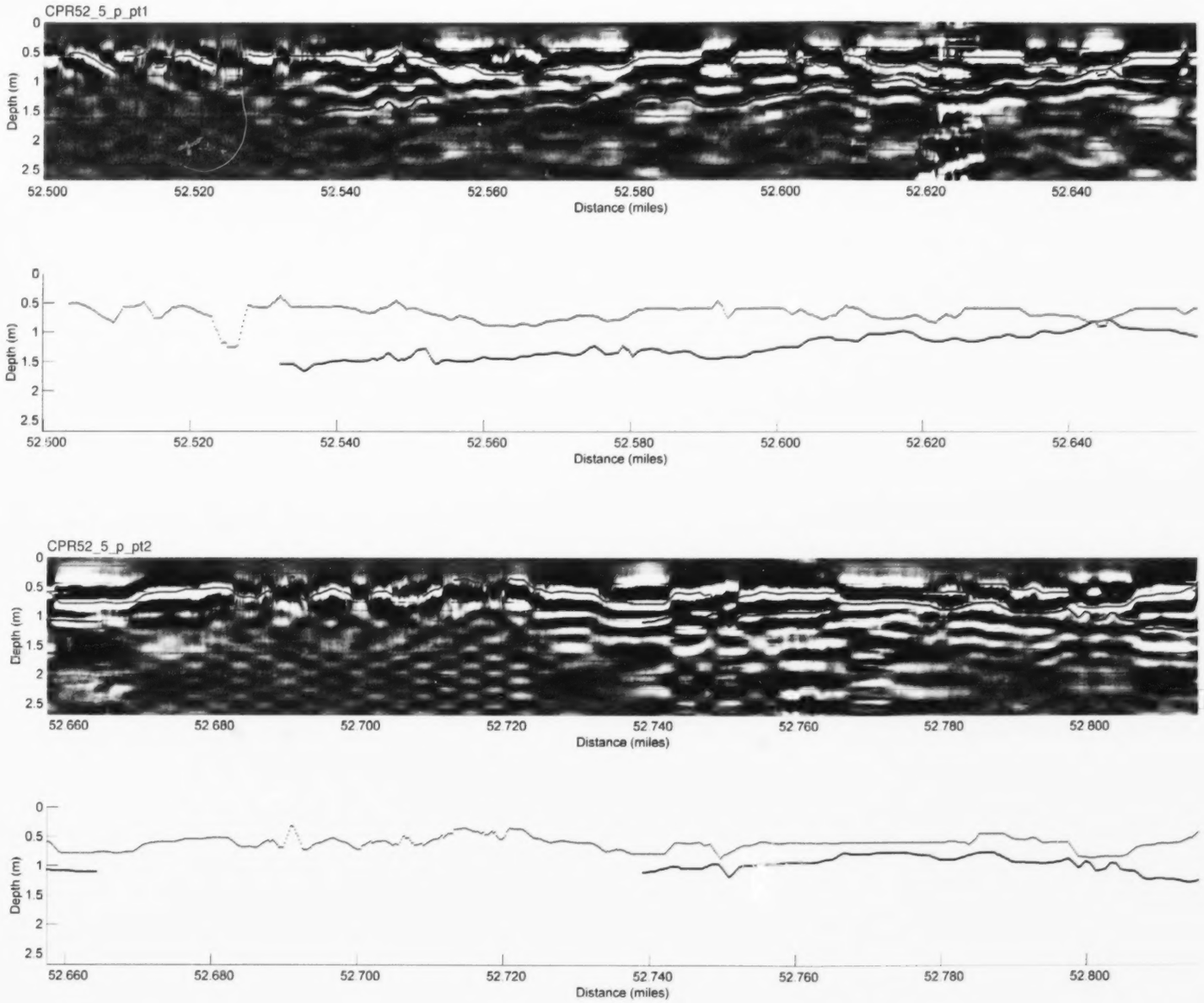
LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

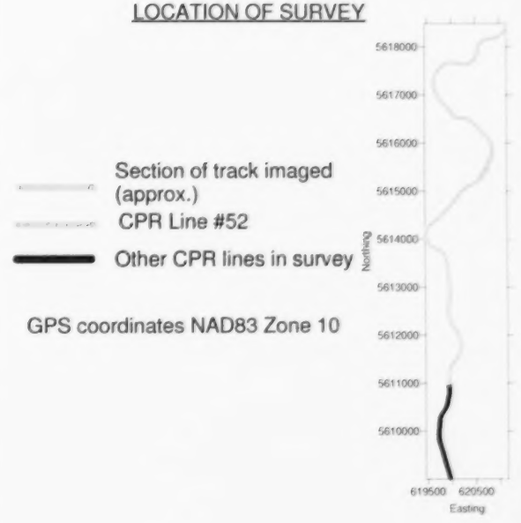
IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 49: CPR52_5a: 500 MHz GPR Data
Mile 52.50 to Mile 52.82



LOCATION OF SURVEY



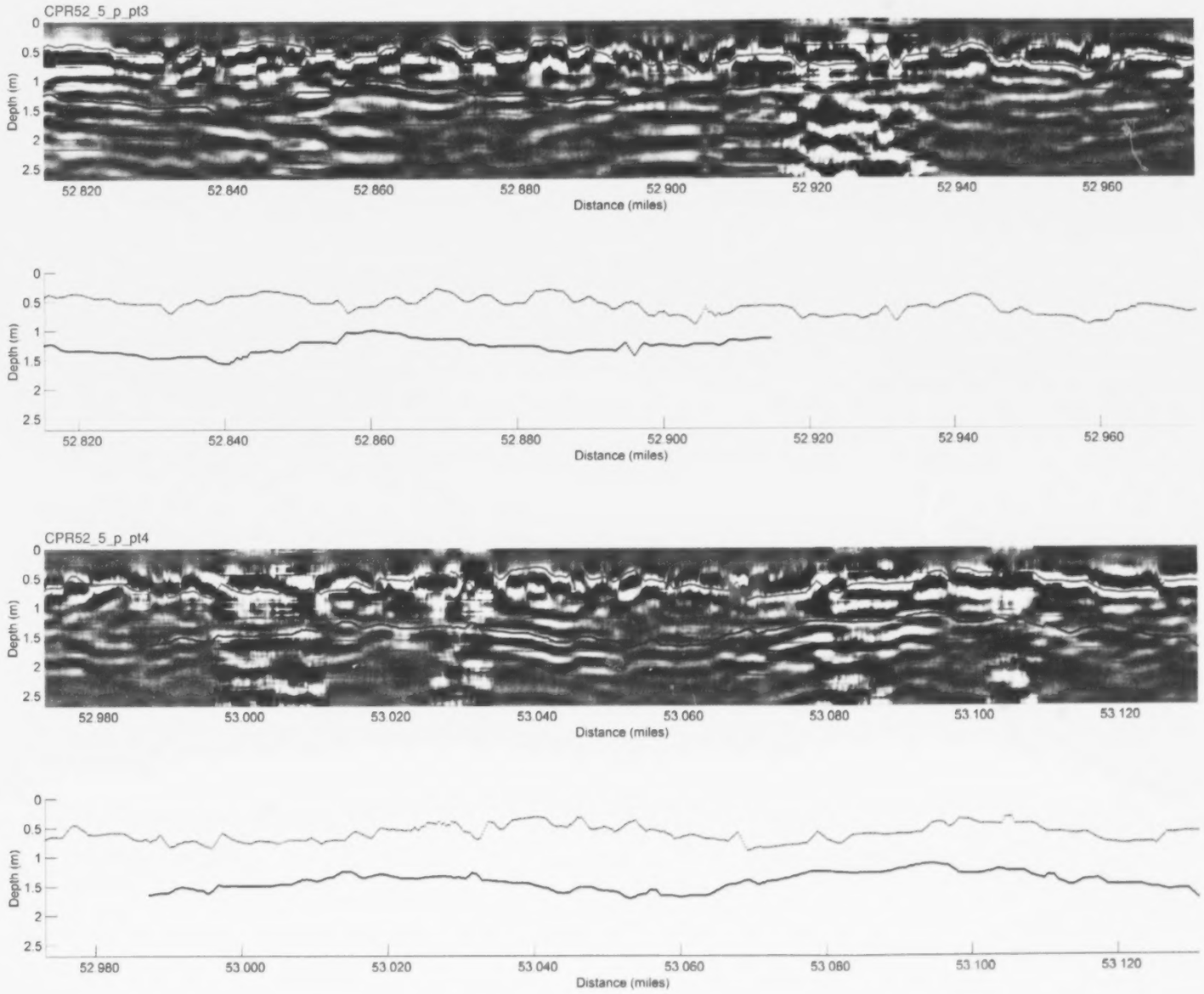
LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

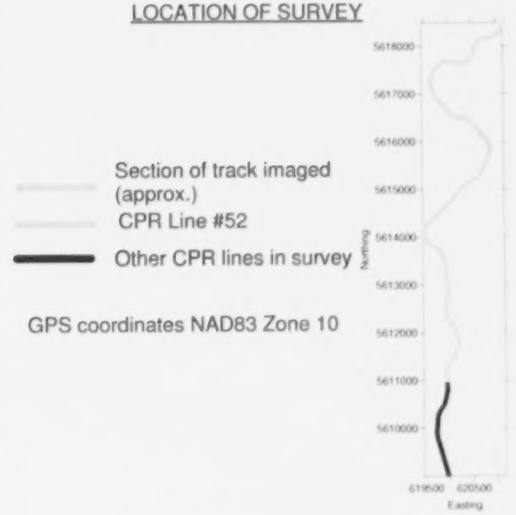
IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 50: CPR52_5b: 500 MHz GPR Data
Mile 52.82 to Mile 53.12



LOCATION OF SURVEY



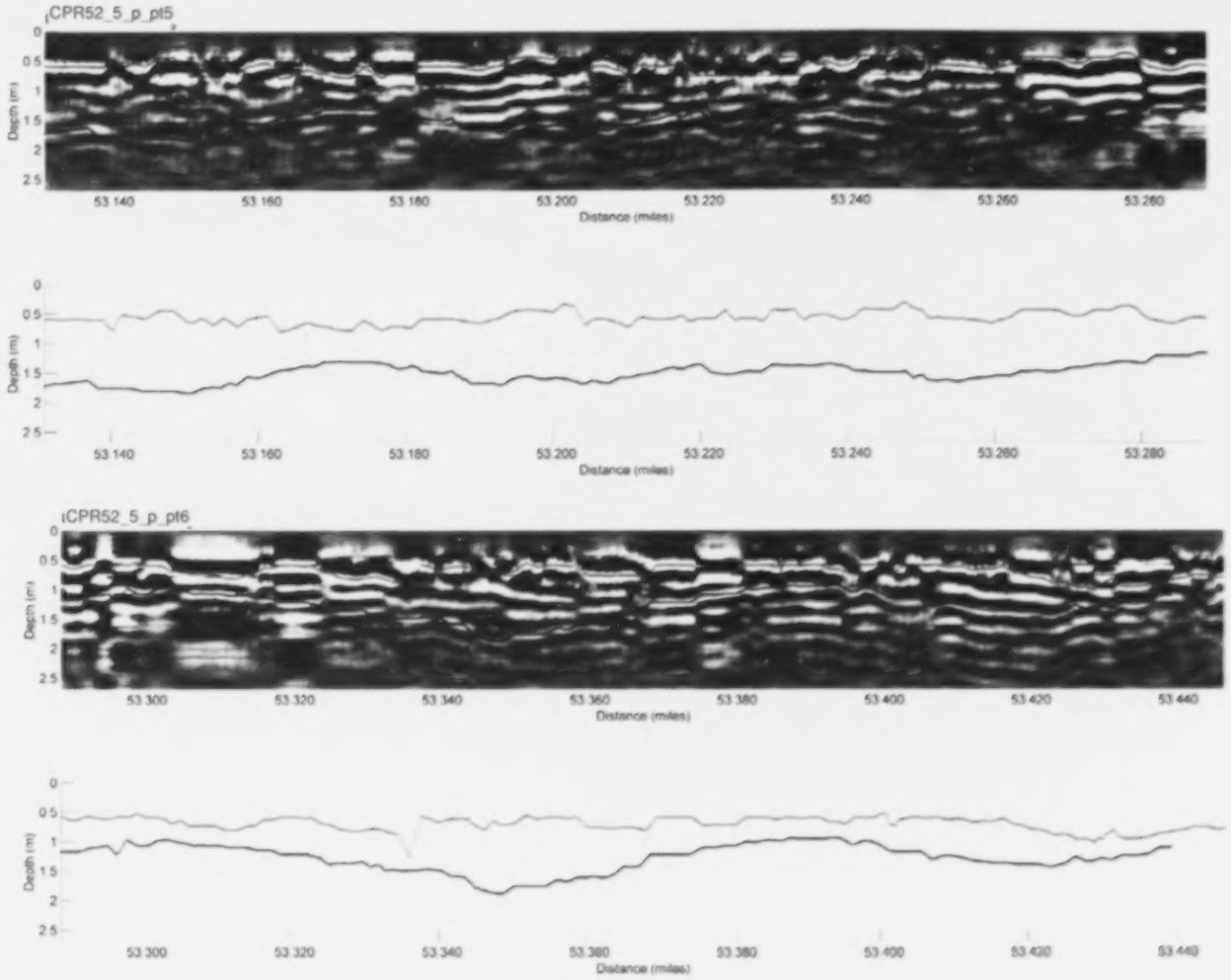
LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 51: CPR52_5c: 500 MHz GPR Data
Mile 53.12 to Mile 53.50



LOCATION OF SURVEY

Section of track imaged (approx.)
CPR Line #52
Other CPR lines in survey

GPS coordinates NAD83 Zone 10

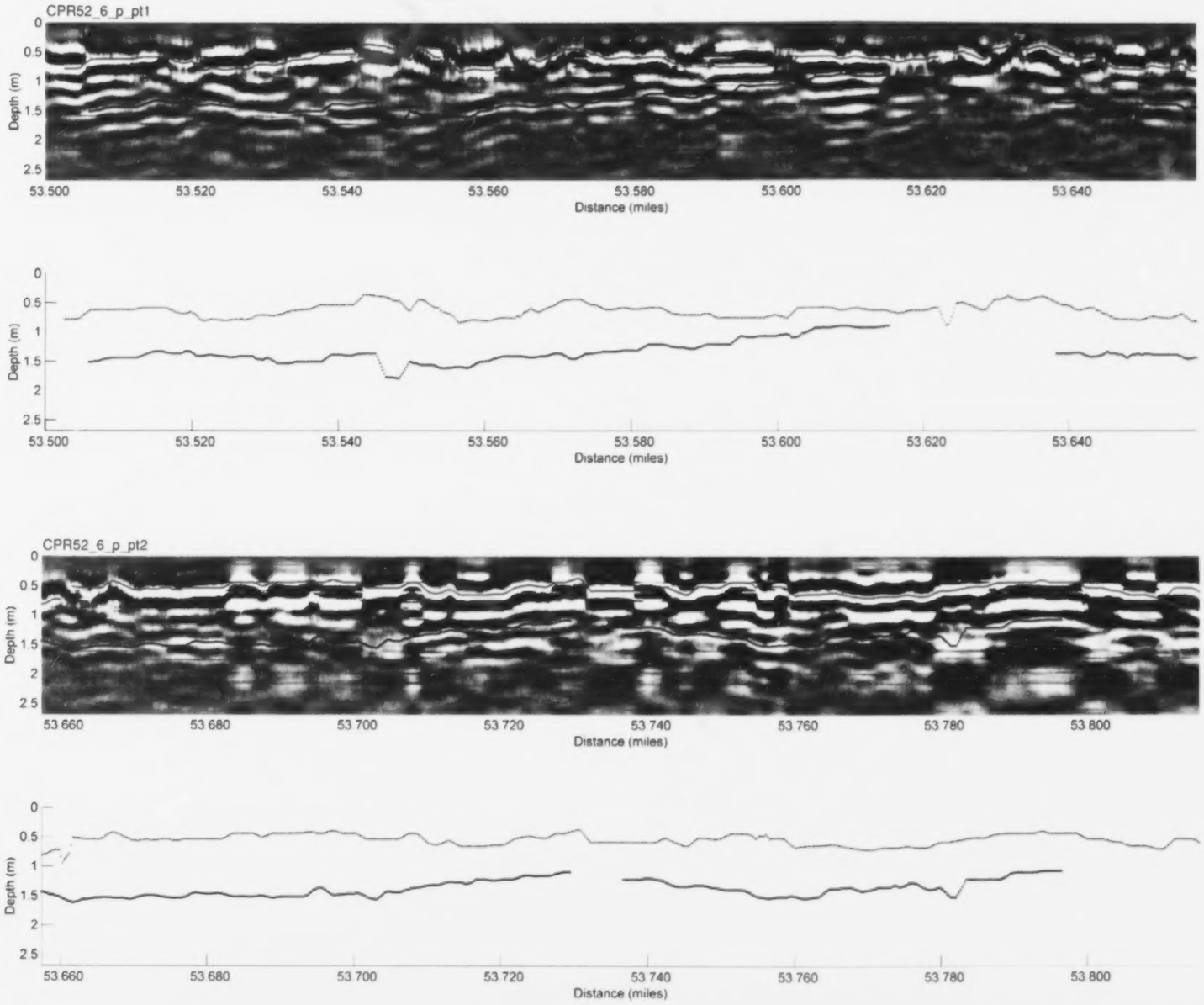
LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

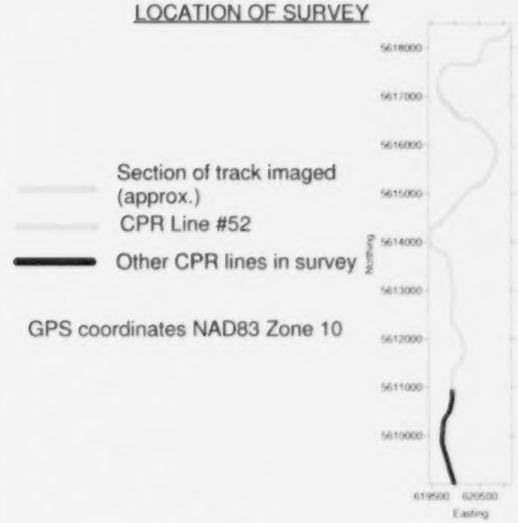
IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 52: CPR52_6a: 500 MHz GPR Data
Mile 53.50 to Mile 53.82



LOCATION OF SURVEY



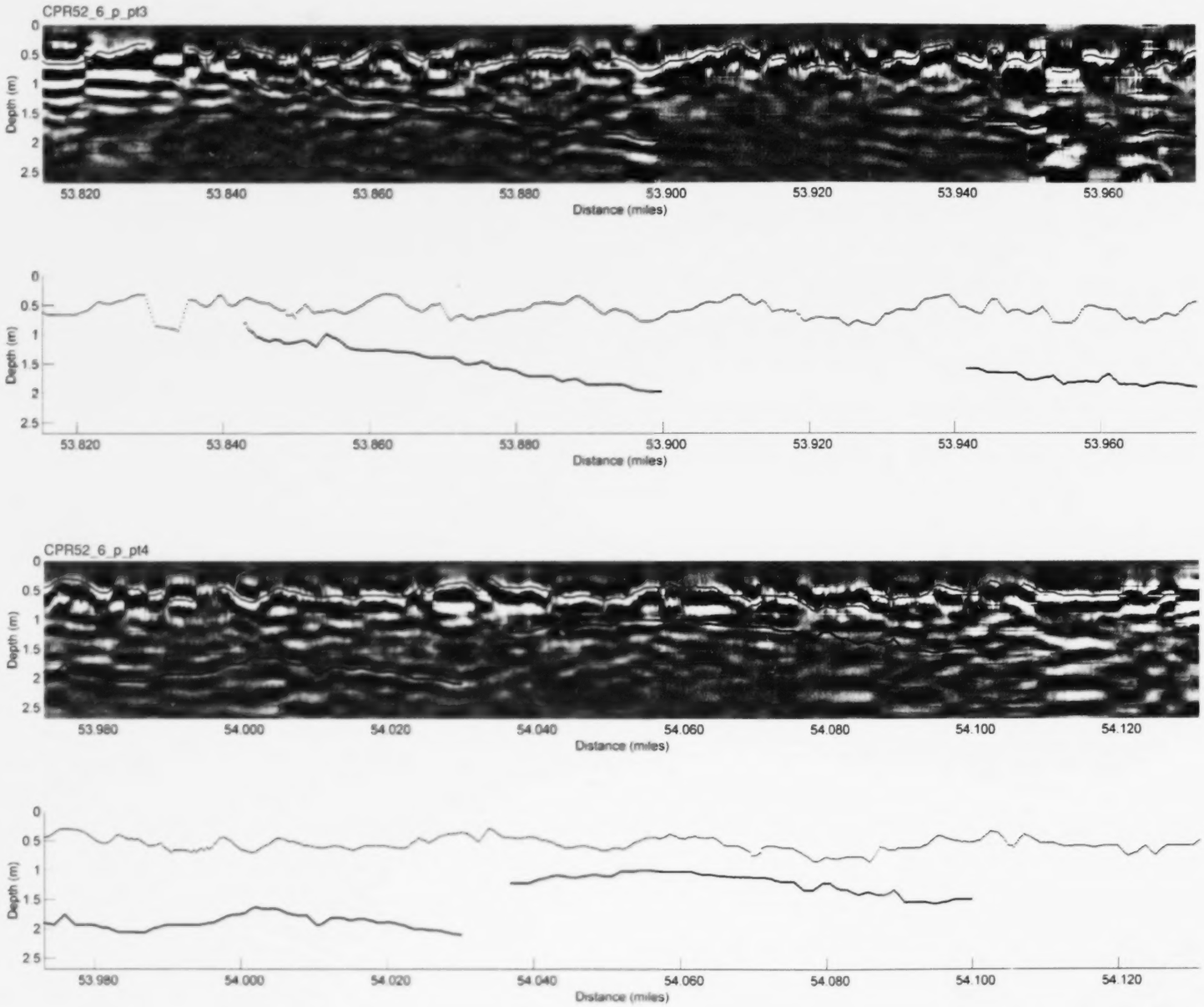
LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

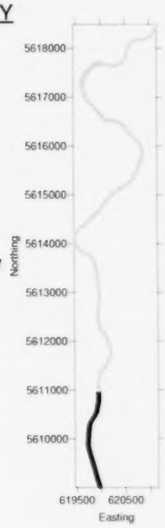
IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 53: CPR52_6b: 500 MHz GPR Data
Mile 53.82 to Mile 54.12



LOCATION OF SURVEY



Section of track imaged (approx.)
CPR Line #52
Other CPR lines in survey

GPS coordinates NAD83 Zone 10

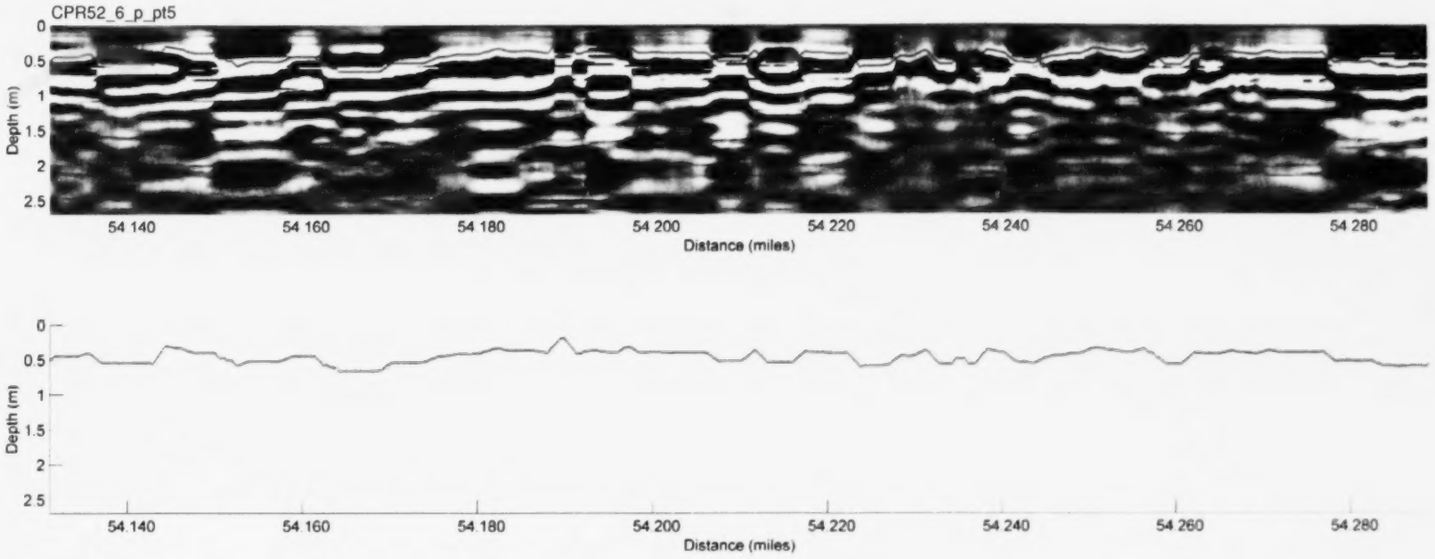
LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

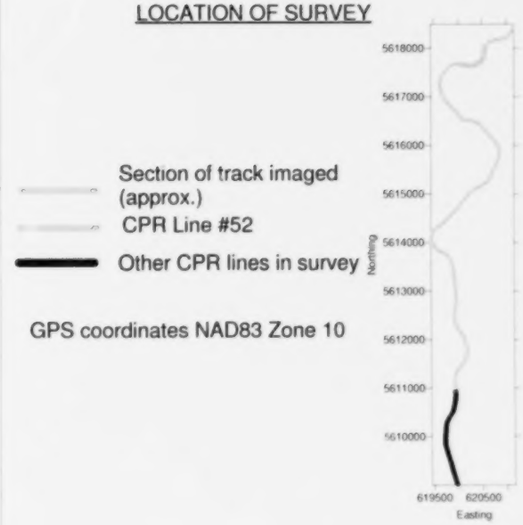
IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 54: CPR52_6c: 500 MHz GPR Data
Mile 54.12 to Mile 54.44



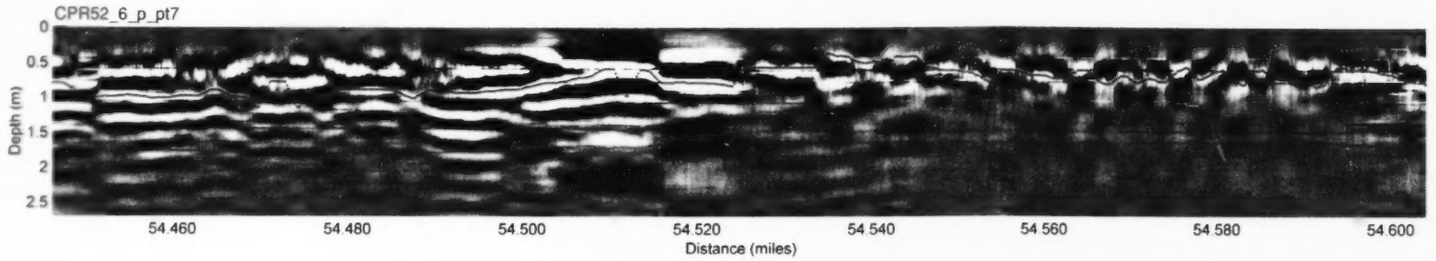
LOCATION OF SURVEY

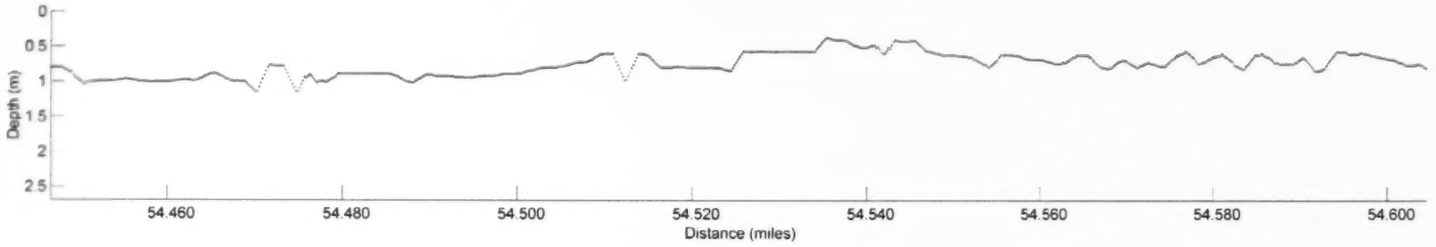


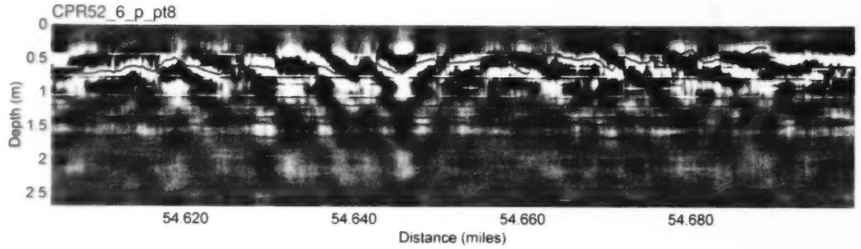
LEGEND

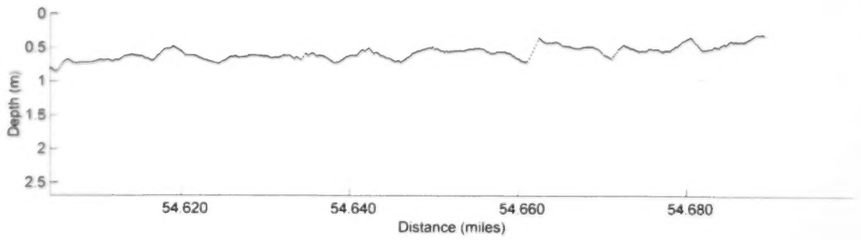
Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.





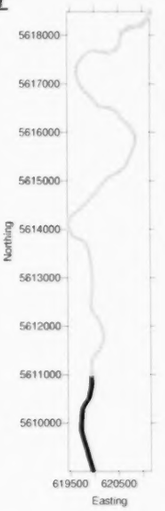




Ballast Investigation
Ground-Penetrating Radar
CPR Rail Line, Ashcroft, B.C.

FIG. 55: CPR52_6d: 500 MHz GPR Data
Mile 54.44 to Mile 54.70

LOCATION OF SURVEY



Section of track imaged (approx.)
CPR Line #52
Other CPR lines in survey

GPS coordinates NAD83 Zone 10

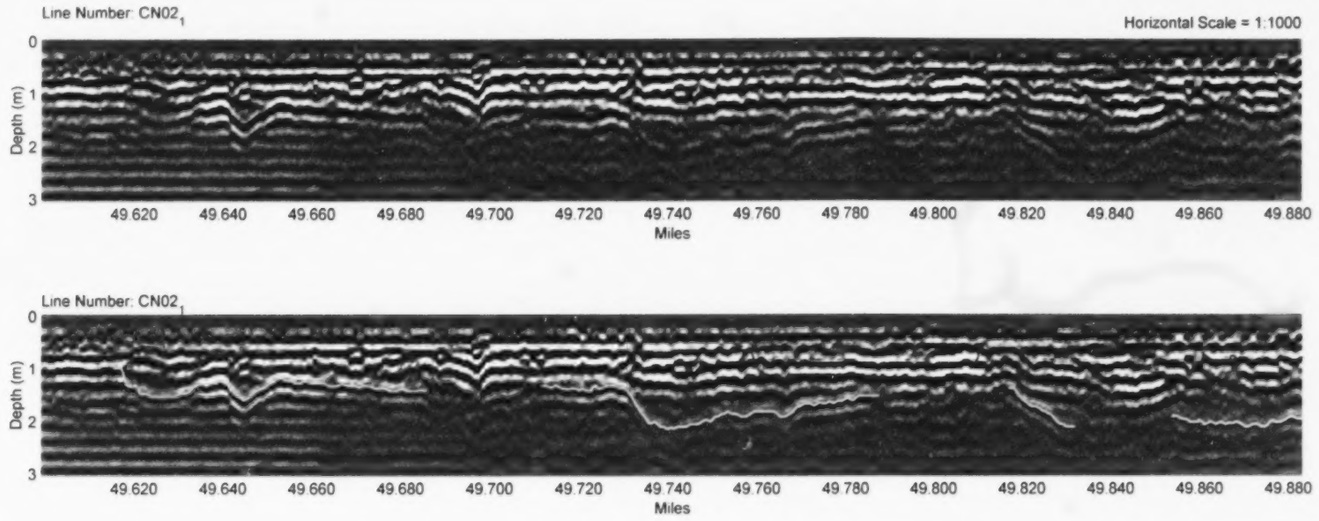
LEGEND

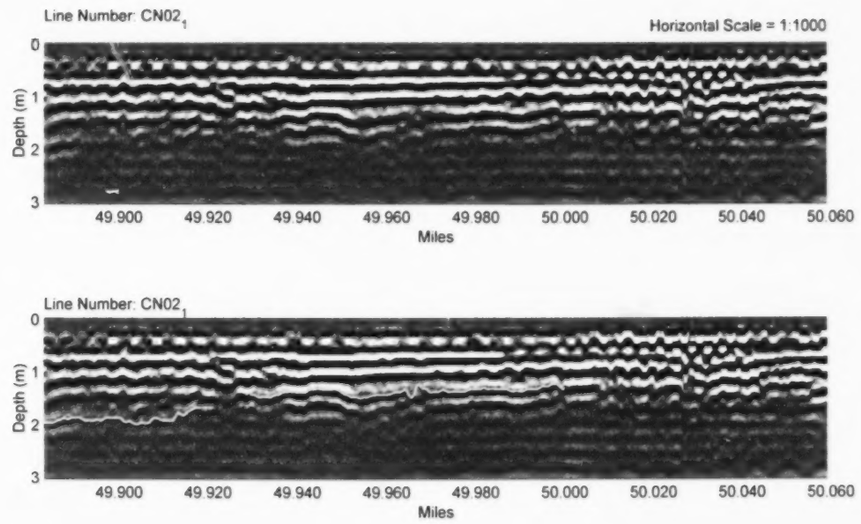
Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CN Rail Line, Ashcroft, B.C.

FIG. 56: CN02: 250 MHz GPR Data
Mile 49.6 to Mile 50.06



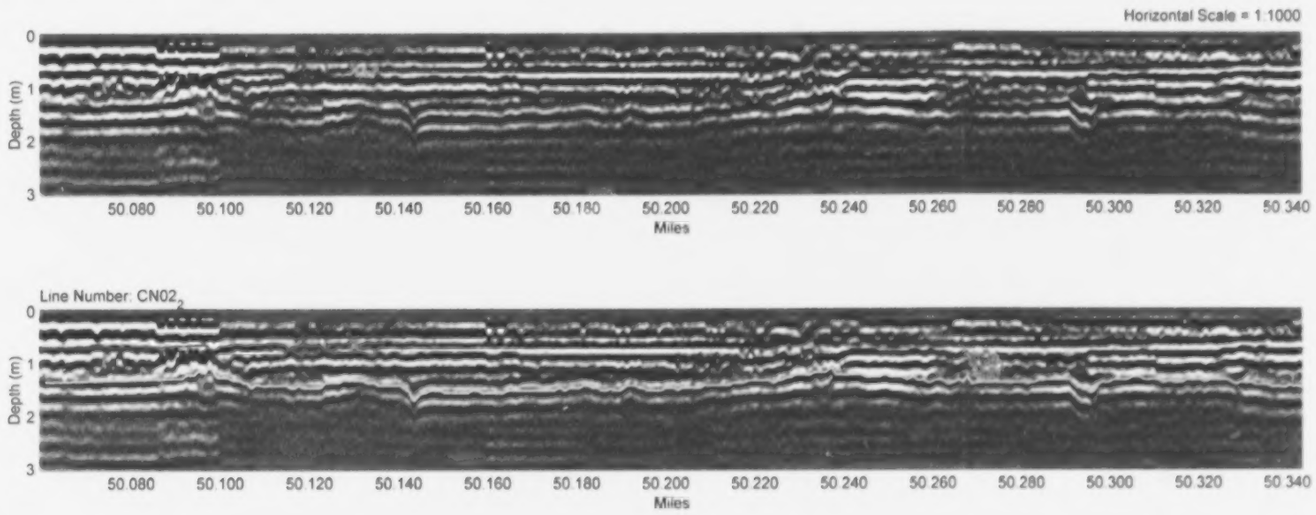


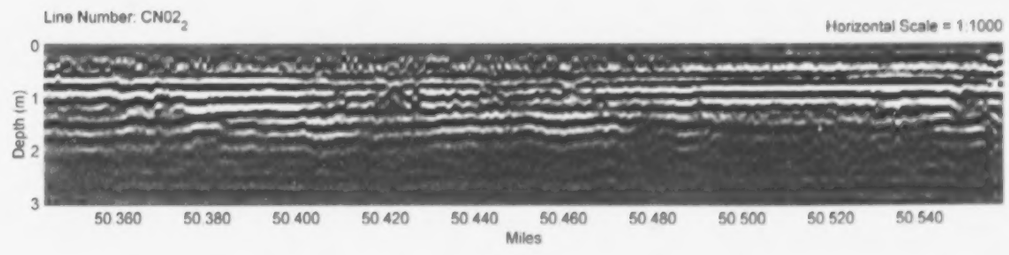
LEGEND

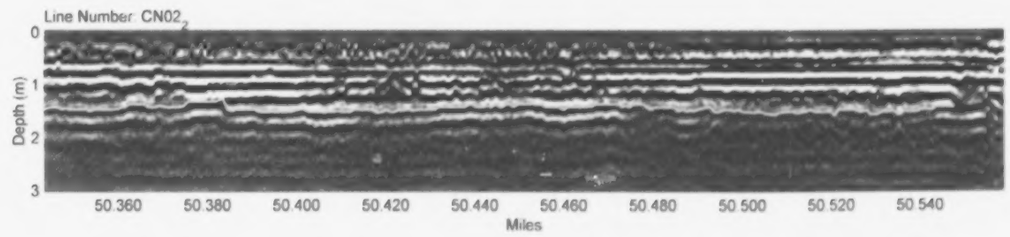
Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.

CN02_2







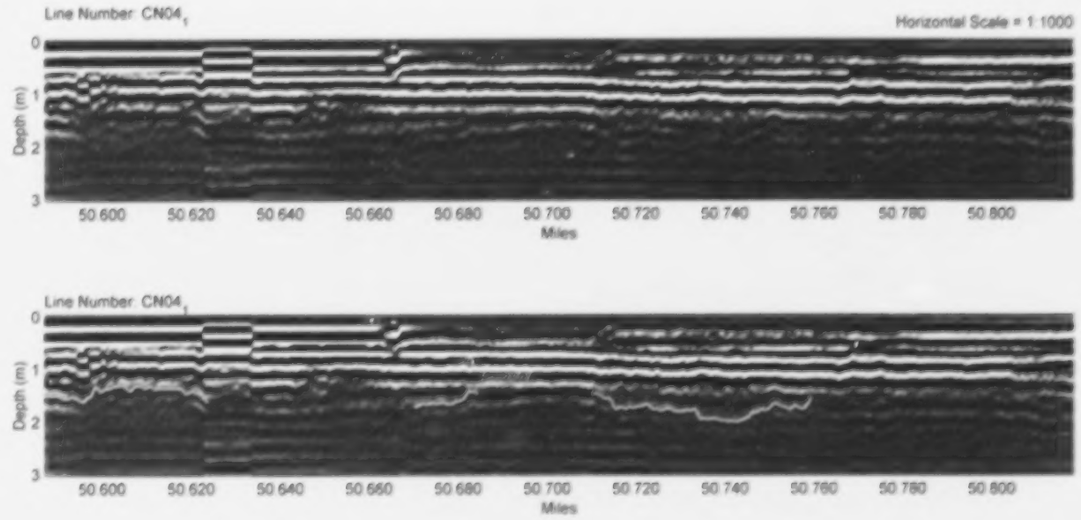
Ballast Investigation
Ground-Penetrating Radar
CN Rail Line, Ashcroft, B.C.

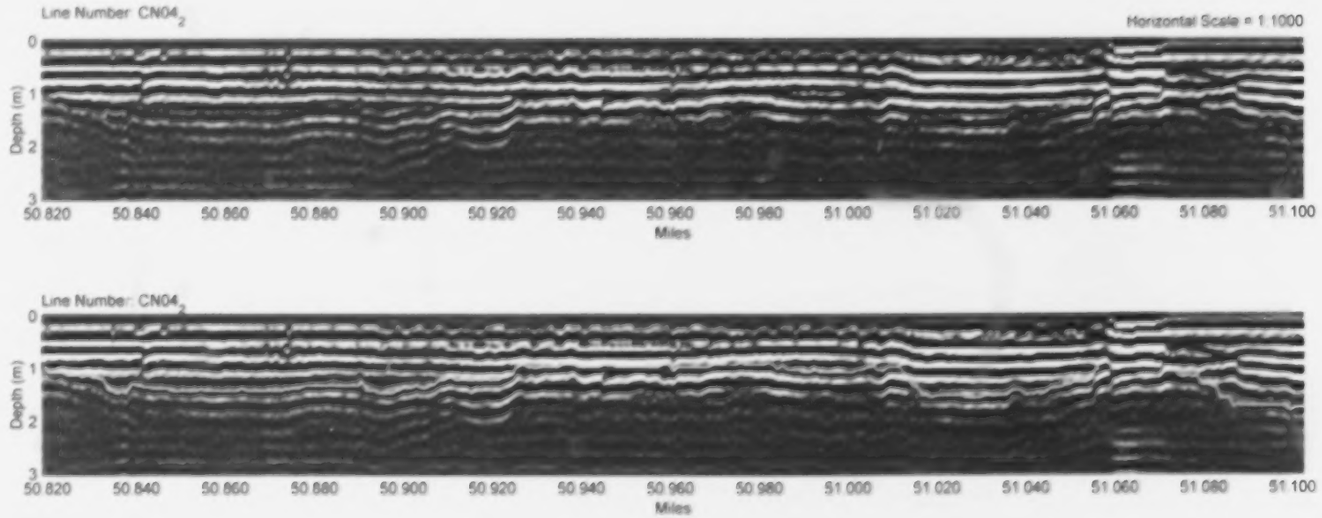
FIG. 57: CN02: 250 MHz GPR Data
Mile 50.06 to Mile 50.56

LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.





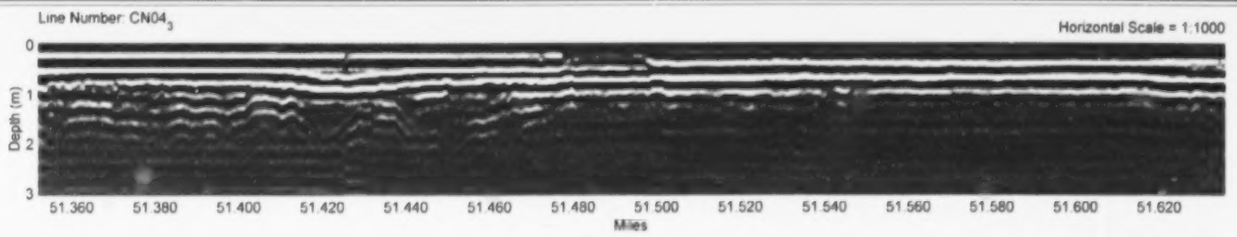
Ballast Investigation
Ground-Penetrating Radar
CN Rail Line, Ashcroft, B.C.

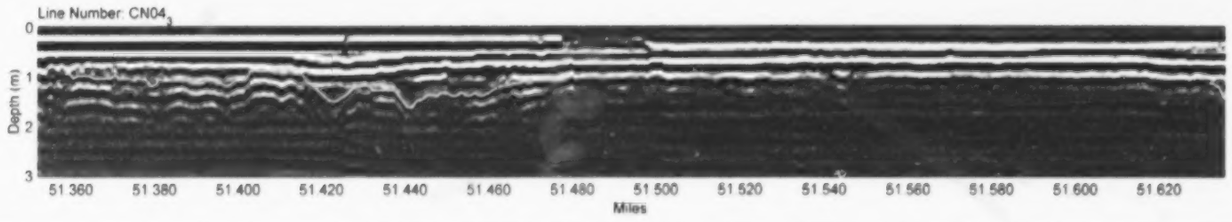
FIG.58: CN04: 250 MHz GPR Data
Mile 50.59 to Mile 51.35

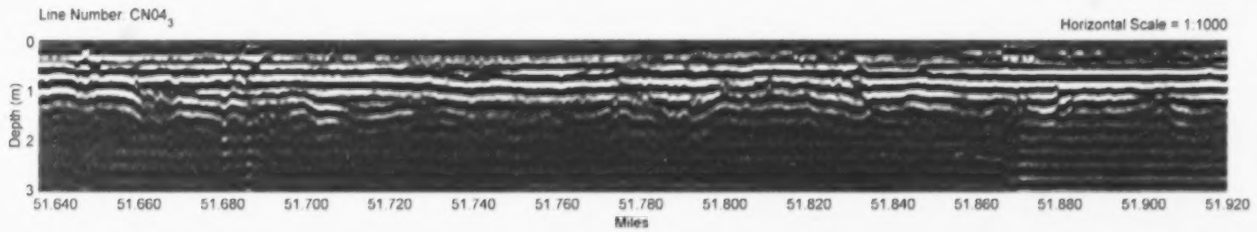
LEGEND

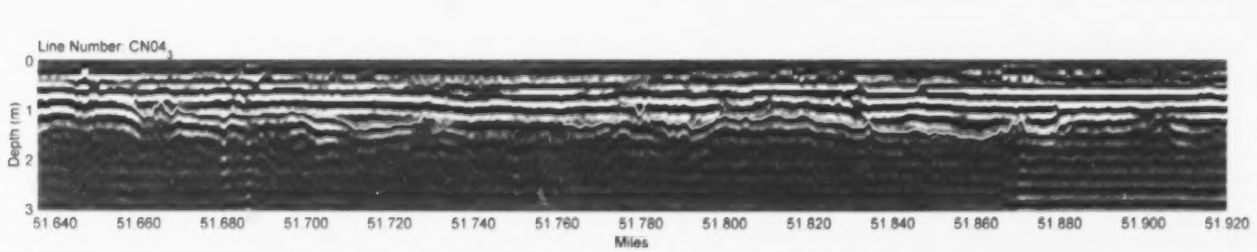
Interpreted base of ballast
Interpreted base of sub-ballast

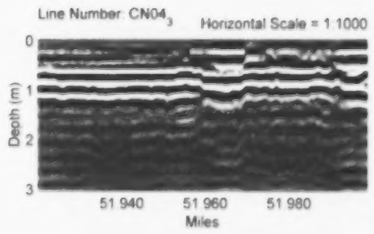
IMC
Associated Mining Consultants Ltd.

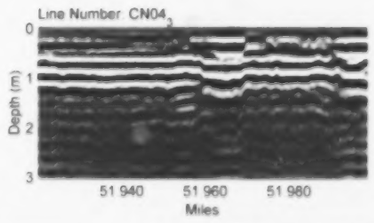












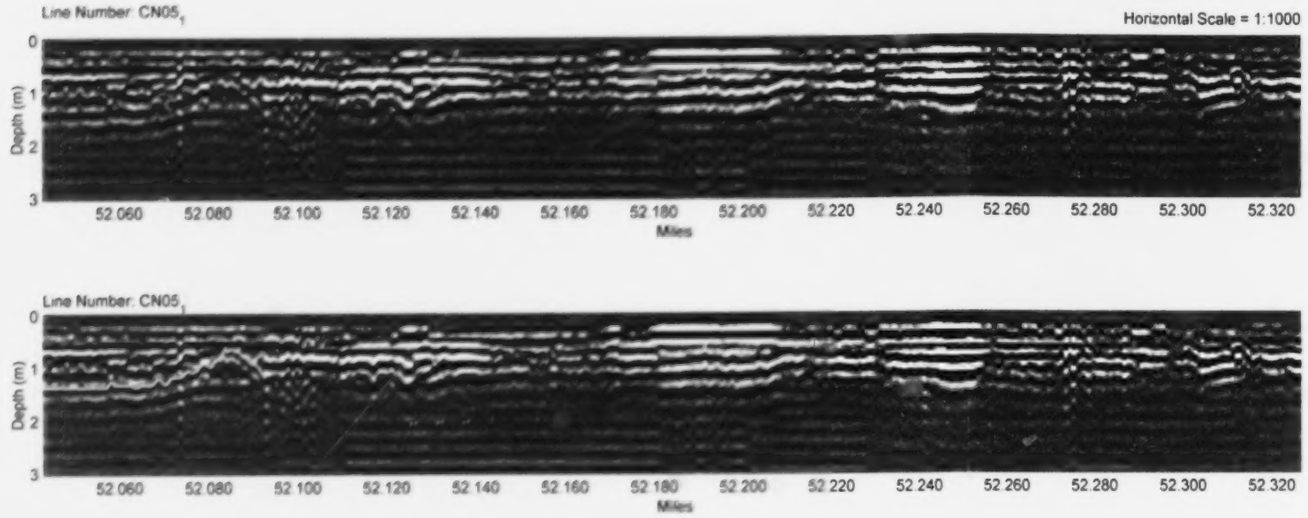
Ballast Investigation
Ground-Penetrating Radar
CN Rail Line, Ashcroft, B.C.

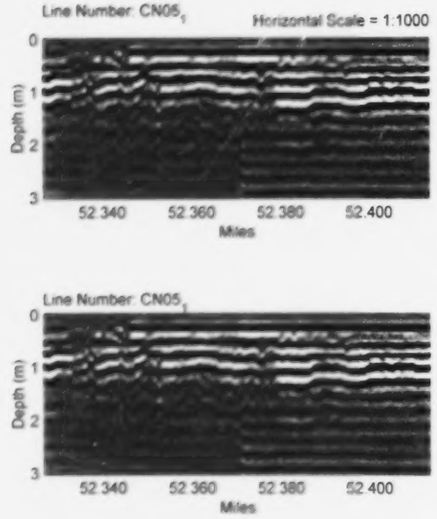
FIG. 59: CN04: 250 MHz GPR Data
Mile 51.36 to Mile 52.0

LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.





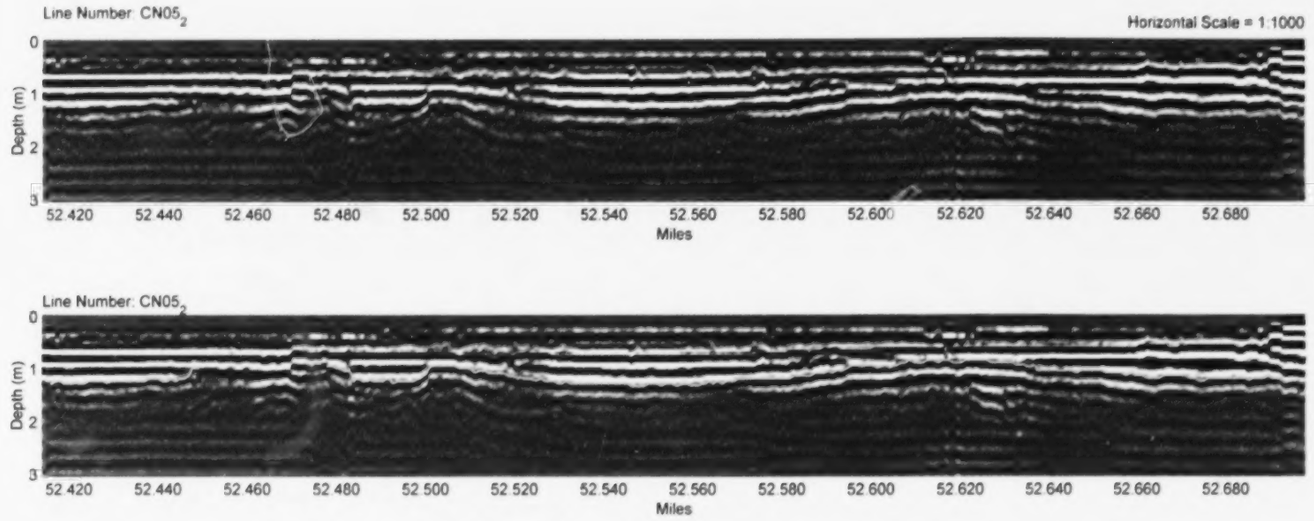
Ballast Investigation
Ground-Penetrating Radar
CN Rail Line, Ashcroft, B.C.

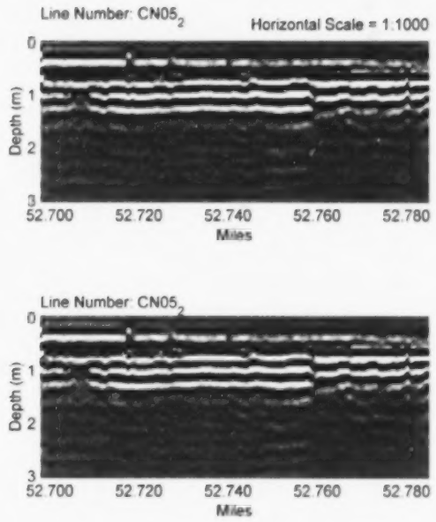
FIG. 60: CN05: 250 MHz GPR Data
Mile 52.04 to Mile 52.41

LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.





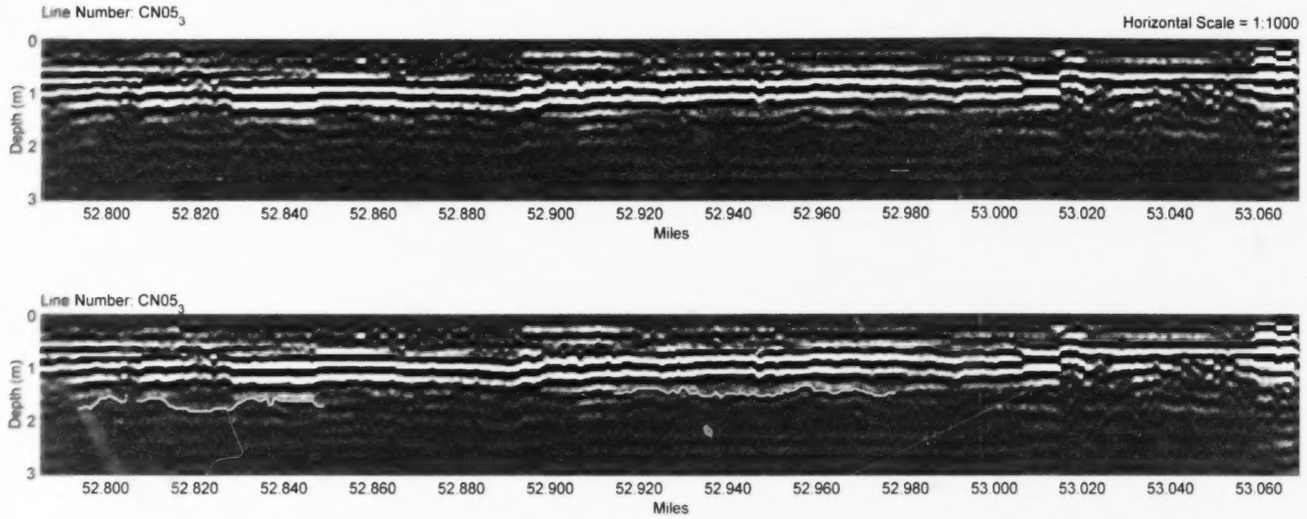
Ballast Investigation
Ground-Penetrating Radar
CN Rail Line, Ashcroft, B.C.

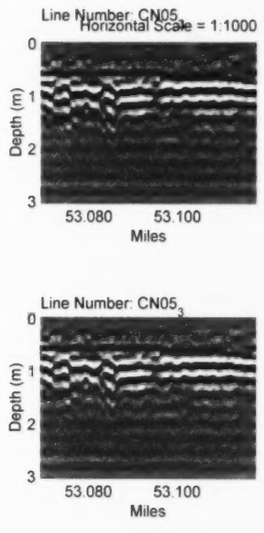
FIG. 61: CN05: 250 MHz GPR Data
Mile 52.41 to Mile 52.78

LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.





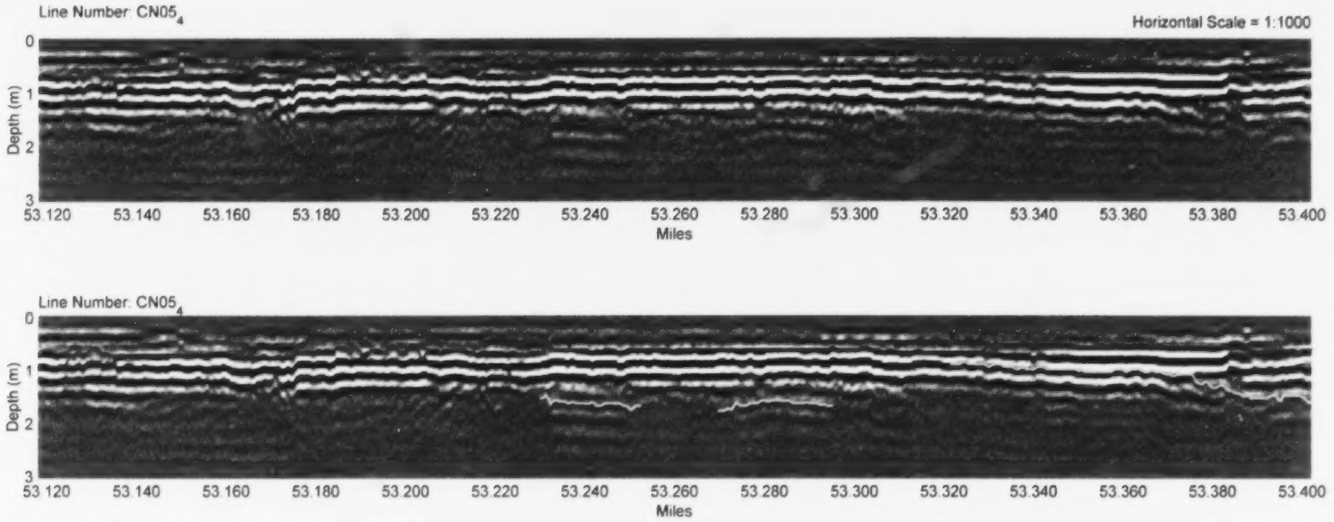
Ballast Investigation
Ground-Penetrating Radar
CN Rail Line, Ashcroft, B.C.

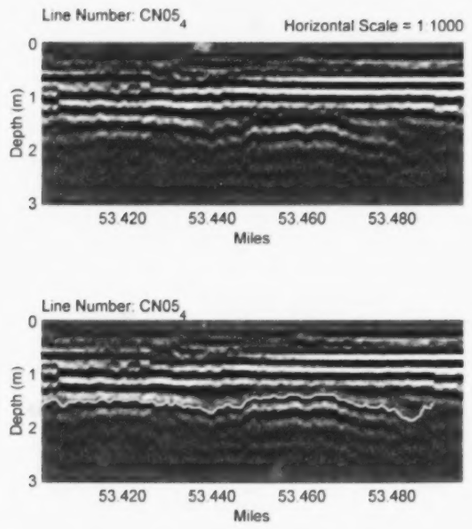
FIG. 62: CN05: 250 MHz GPR Data
Mile 52.79 to Mile 53.12

LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.





Ballast Investigation
Ground-Penetrating Radar
CN Rail Line, Ashcroft, B.C.

FIG. 63: CN05: 250 MHz GPR Data
Mile 53.12 to Mile 53.50

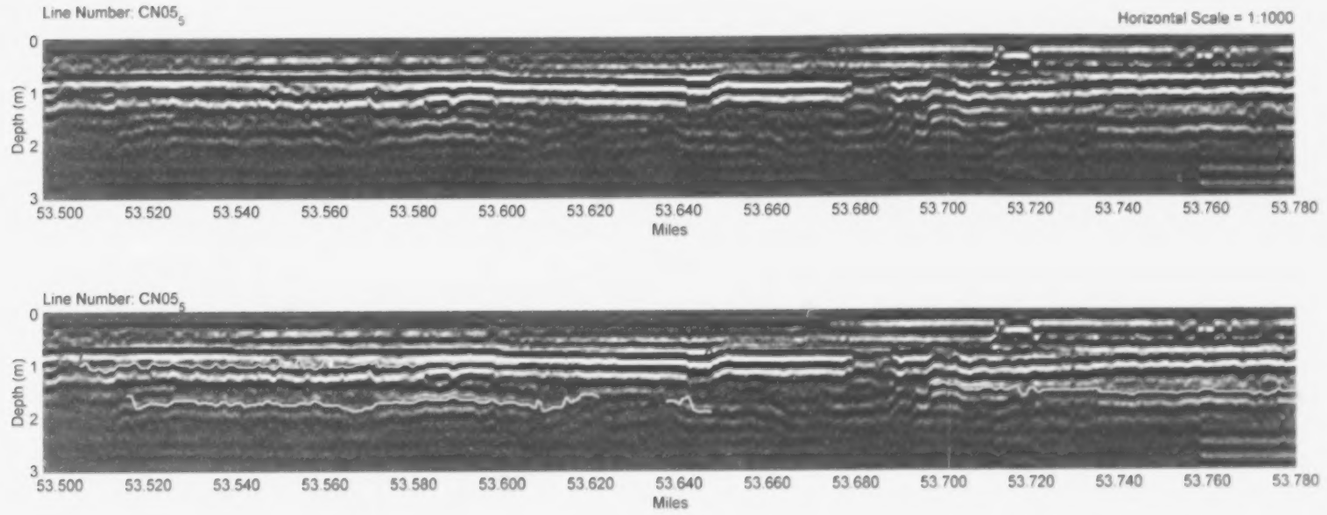
LEGEND

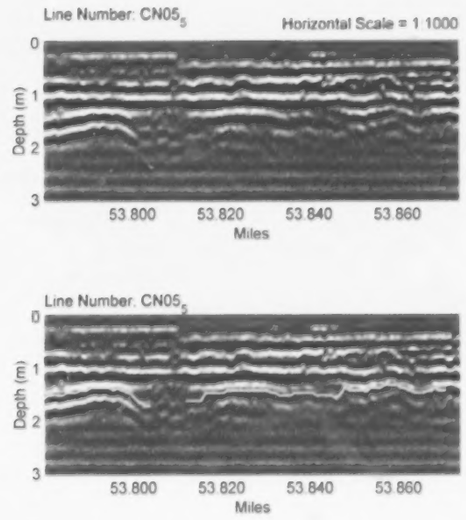
Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CN Rail Line, Ashcroft, B.C.

FIG. 64: CN05: 250 MHz GPR Data
Mile 53.50 to Mile 53.87

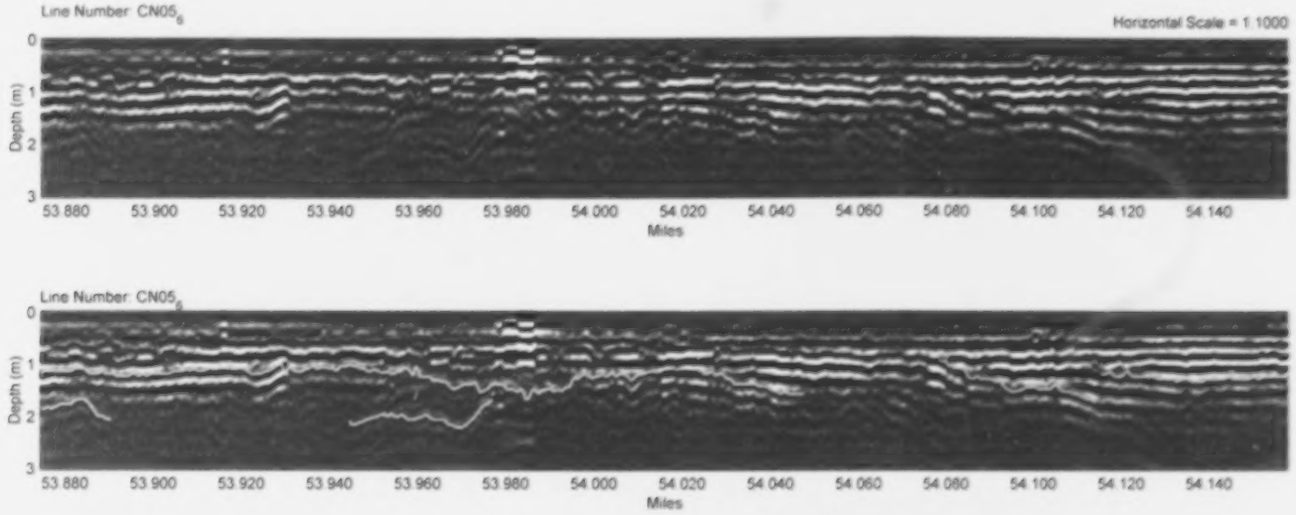


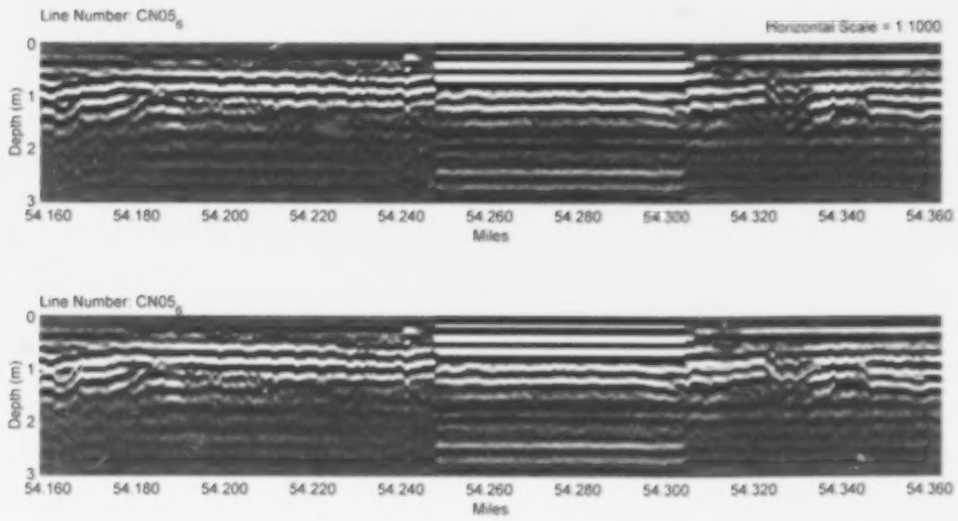


LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast
Reflection within ballast

IMC
Associated Mining Consultants Ltd.





Ballast Investigation
Ground-Penetrating Radar
CN Rail Line, Ashcroft, B.C.

FIG. 65: CN05: 250 MHz GPR Data
Mile 53.87 to Mile 54.36

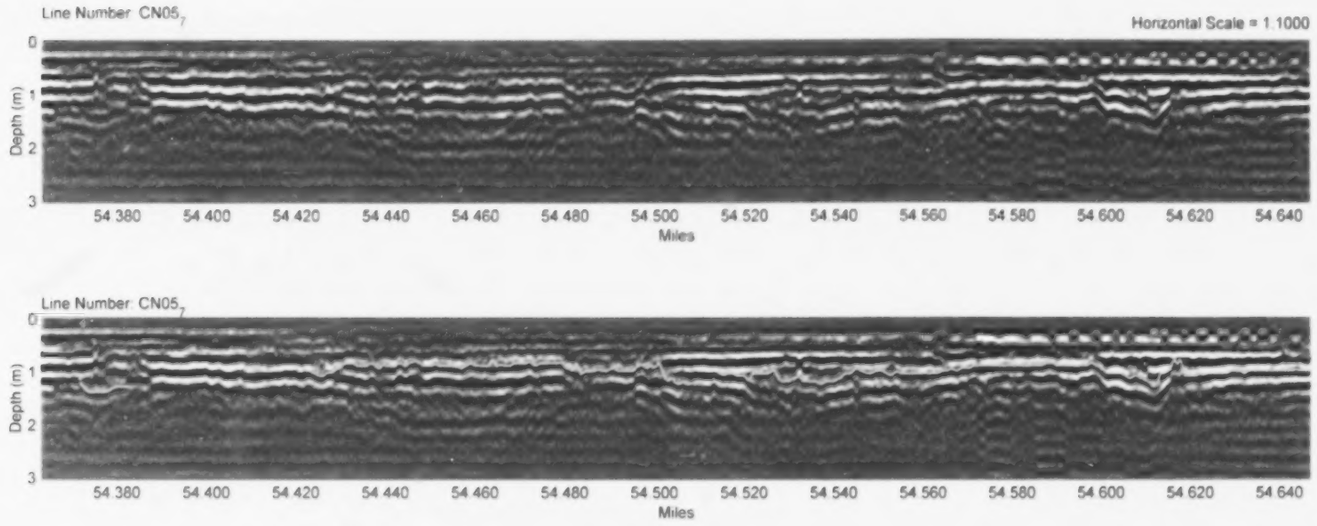
LEGEND

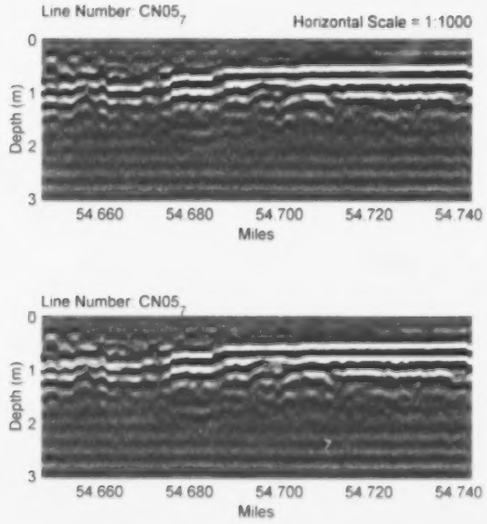
Interpreted base of ballast
Interpreted base of sub-ballast
Location from unidentified deeper horizon

IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CN Rail Line, Ashcroft, B.C.

FIG. 66: CN05: 250 MHz GPR Data
Mile 54.37 to Mile 54.74





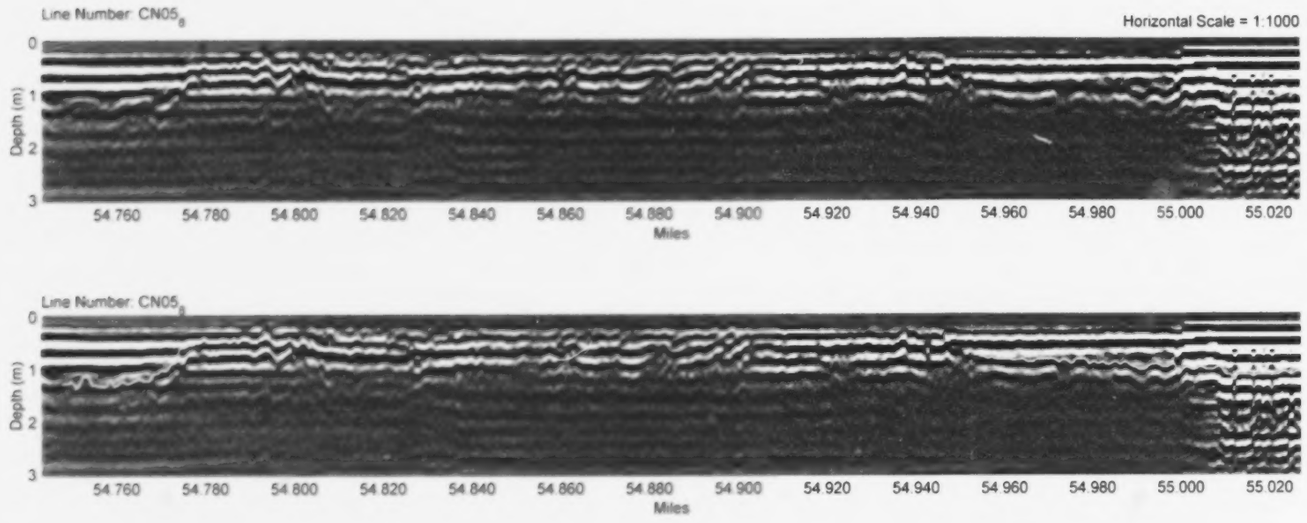
LEGEND

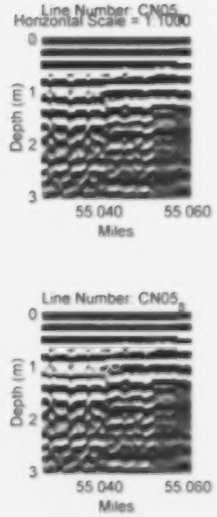
Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CN Rail Line, Ashcroft, B.C.

FIG. 67: CN05: 250 MHz GPR Data
Mile 54.75 to Mile 55.06





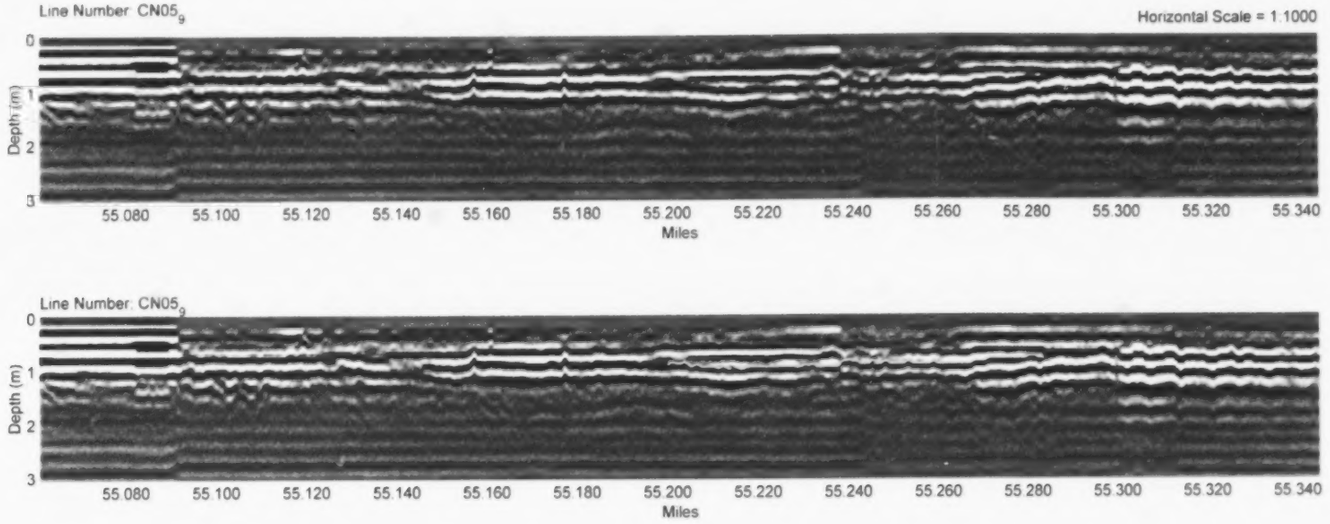
LEGEND

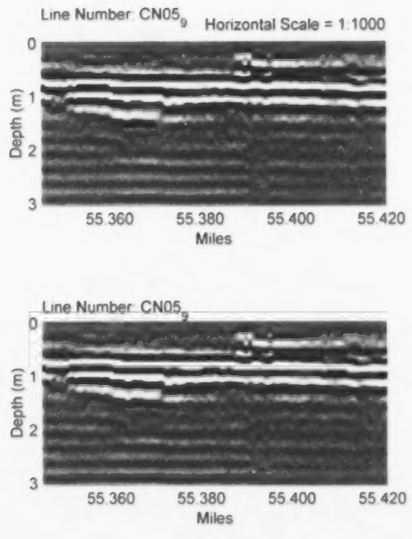
Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CN Rail Line, Ashcroft, B.C.

FIG. 68: CN05: 250 MHz GPR Data
Mile 55.06 to Mile 55.42

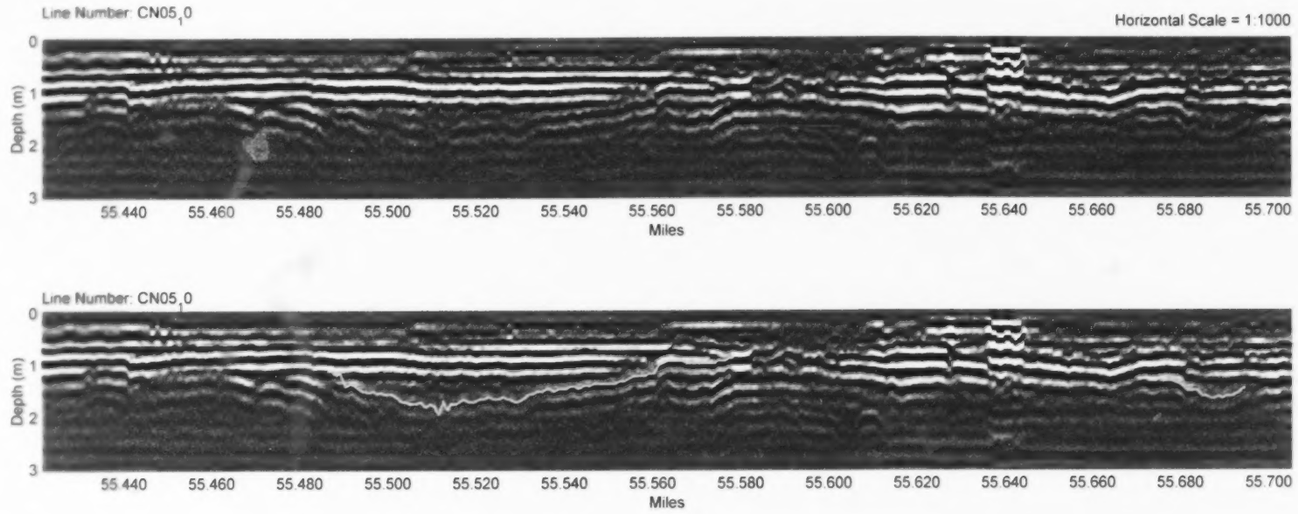


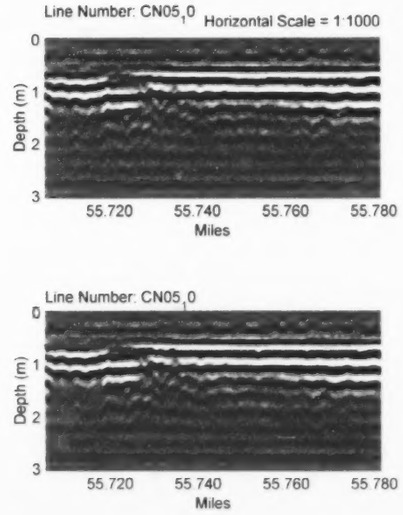


LEGEND

Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.





Ballast Investigation
Ground-Penetrating Radar
CN Rail Line, Ashcroft, B.C.

FIG. 69: CN05: 250 MHz GPR Data
Mile 55.42 to Mile 55.78

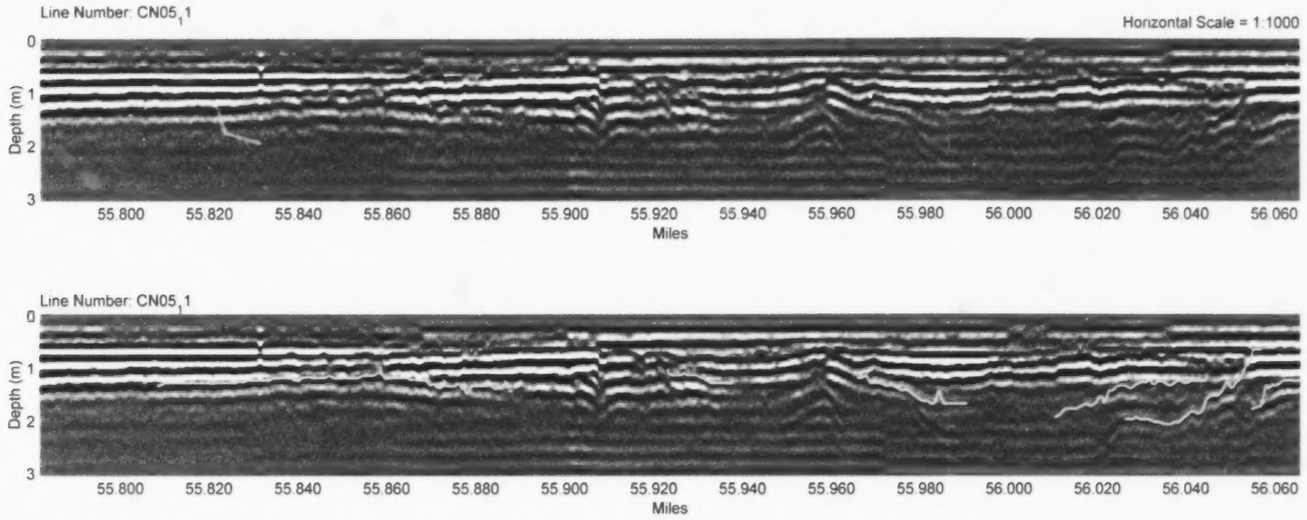
LEGEND

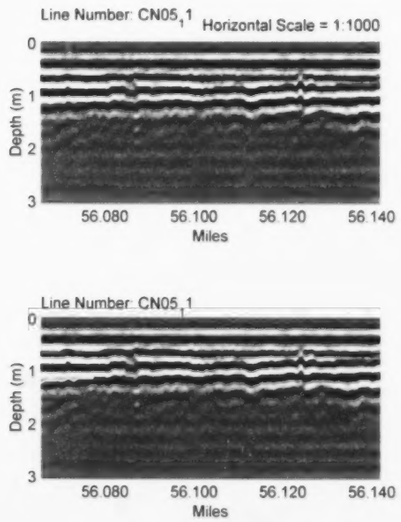
Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CN Rail Line, Ashcroft, B.C.

FIG. 70: CN05: 250 MHz GPR Data
Mile 55.78 to Mile 56.14





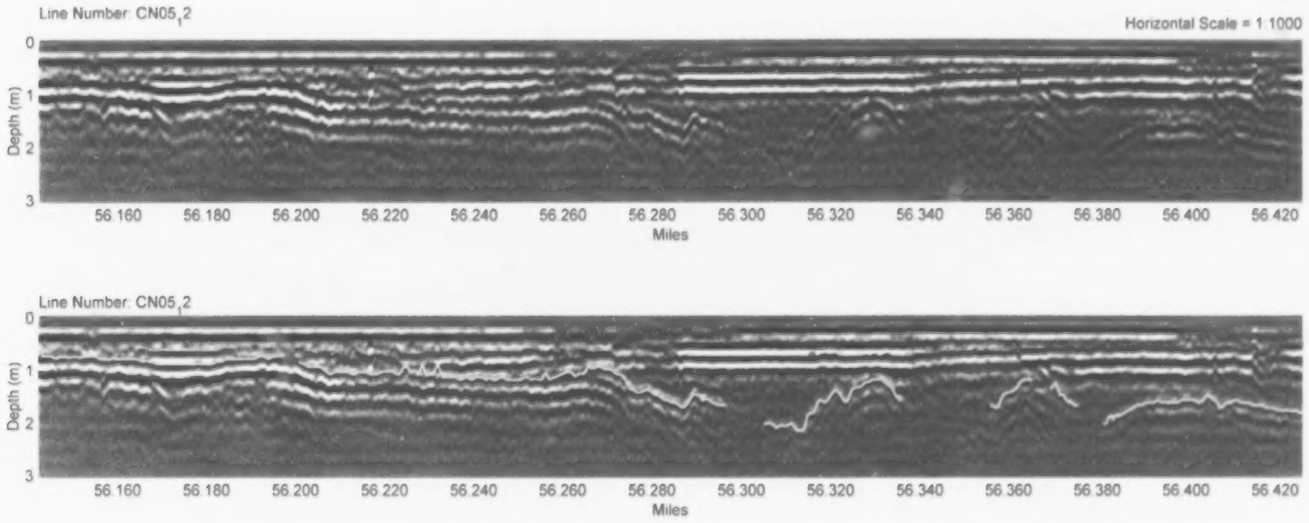
LEGEND

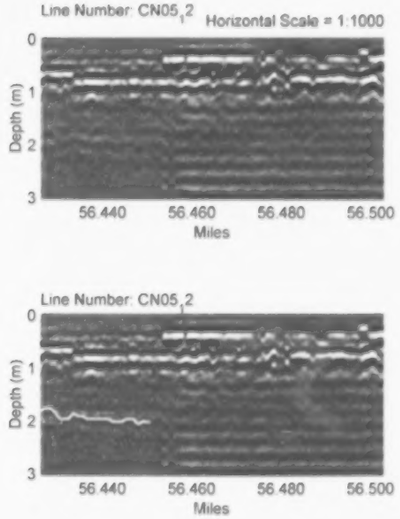
Interpreted base of ballast
Interpreted base of sub-ballast
Reflection from unknown horizon

IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CN Rail Line, Ashcroft, B.C.

FIG. 71: CN05: 250 MHz GPR Data
Mile 56.14 to Mile 56.50





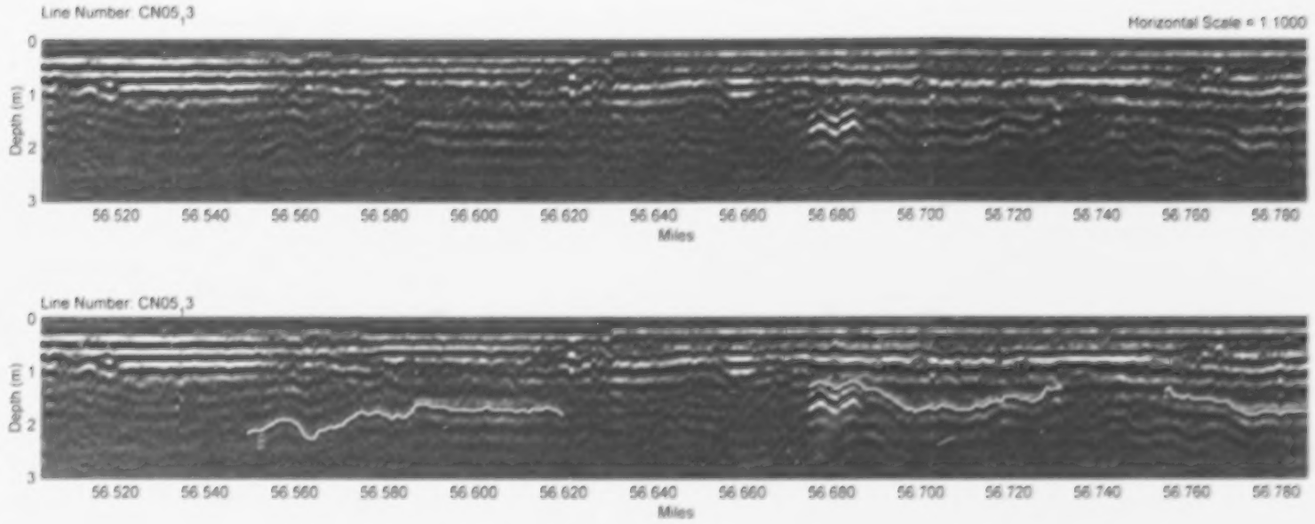
LEGEND

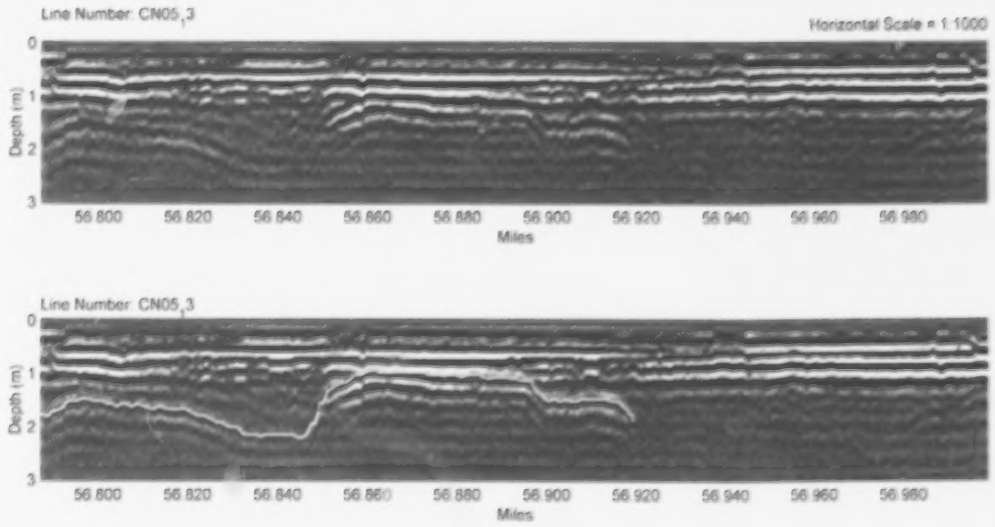
Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CN Rail Line, Ashcroft, B.C.

FIG. 72: CN05: 250 MHz GPR Data
Mile 56.51 to Mile 56.99





LEGEND

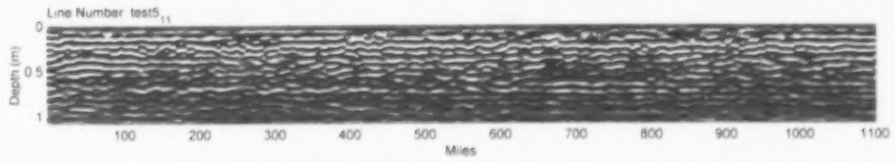
Interpreted base of ballast
Interpreted base of sub-ballast

IMC
Associated Mining Consultants Ltd.

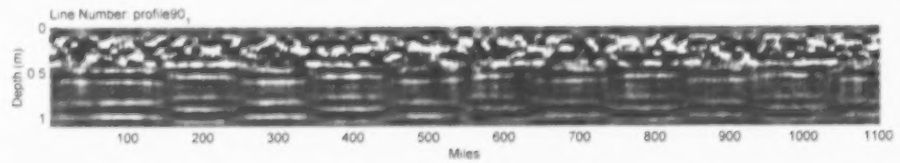
Ballast Investigation
Ground-Penetrating Radar
CN/CPR Rail Line, Ashcroft, B.C.

FIG. 73: Comparison of Antenna Frequencies: 250, 500 and 800 MHz

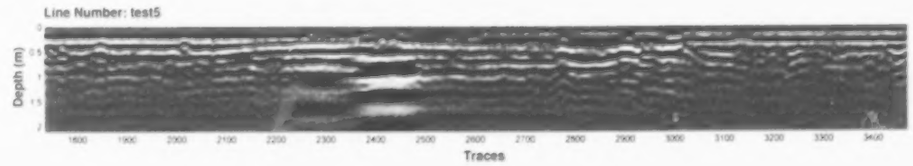
800 MHz



500 MHz



250 MHz

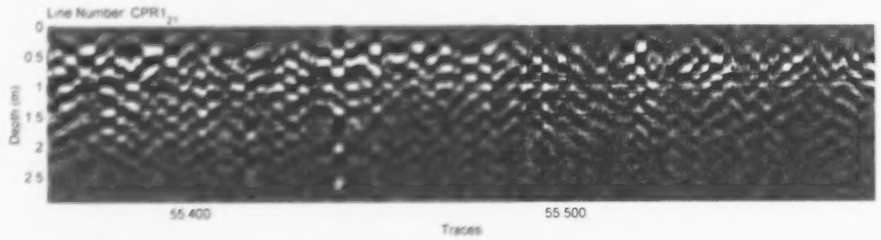


IMC
Associated Mining Consultants Ltd.

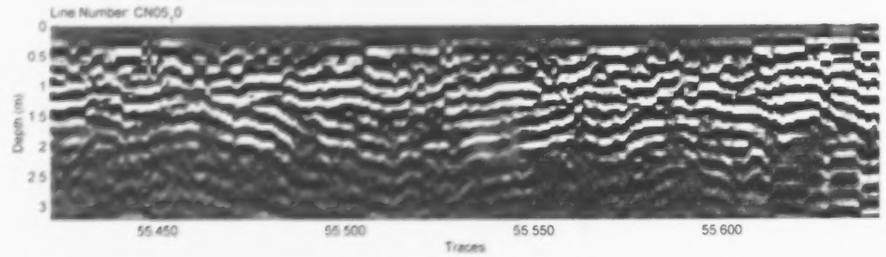
Ballast Investigation
Ground-Penetrating Radar
CN/CPR Rail Line, Ashcroft, B.C.

FIG. 74: Comparison of Antenna Height Above Ballast

Antenna 30 cm above ground



Antenna 5 cm above ground



IMC
Associated Mining Consultants Ltd.

Ballast Investigation
Ground-Penetrating Radar
CN/CPR Rail line, Ashcroft, B.C.

FIG. 75: Comparison of Results at Two Resolutions: 12.43 traces/m and 4.14 traces/m

12.43 traces/m

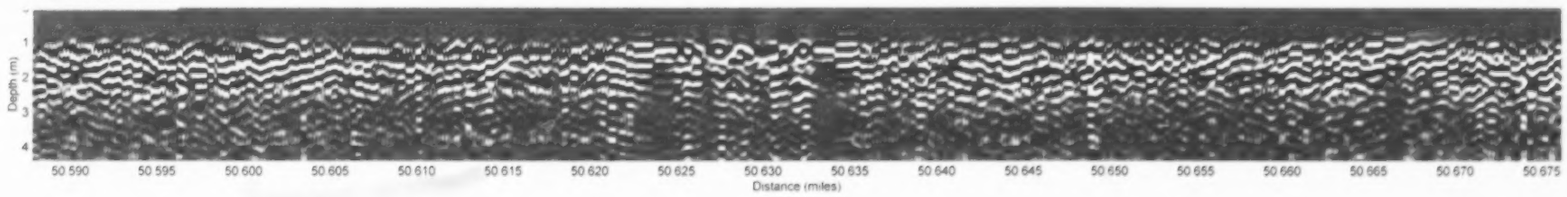


Figure 75a

4.14 traces/m

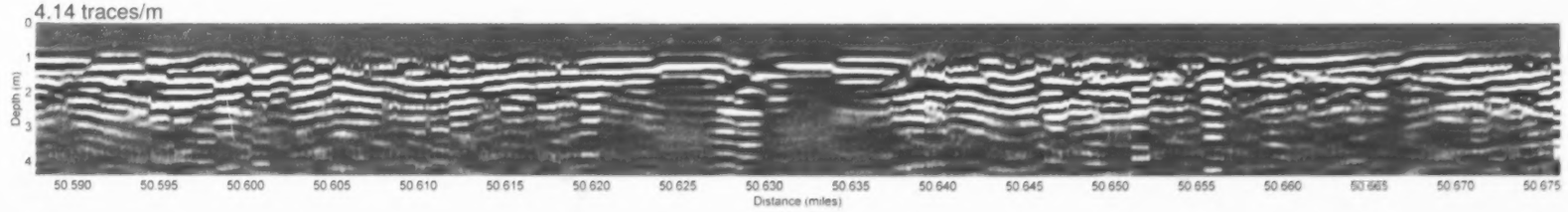


Figure 75b

Public Works and Government Services Canada

Travaux publics et Services gouvernementaux Canada

IMC
Associated Mining Consultants Ltd.

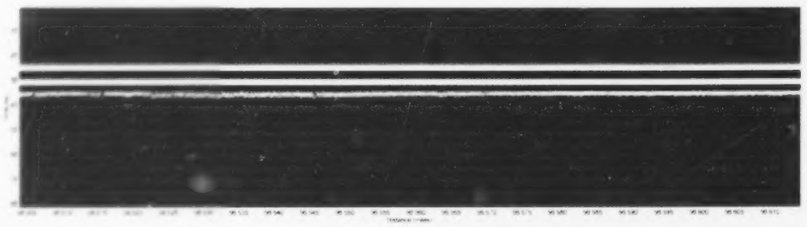


Figure 76a: Raw Data

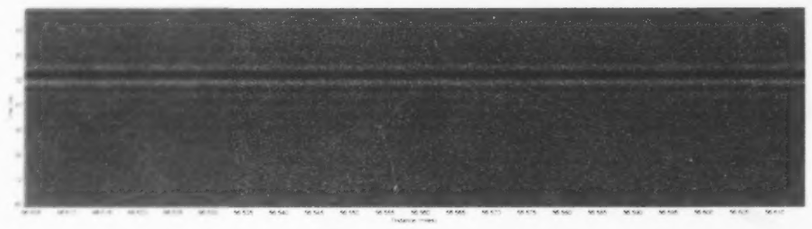


Figure 76b: Balanced Data

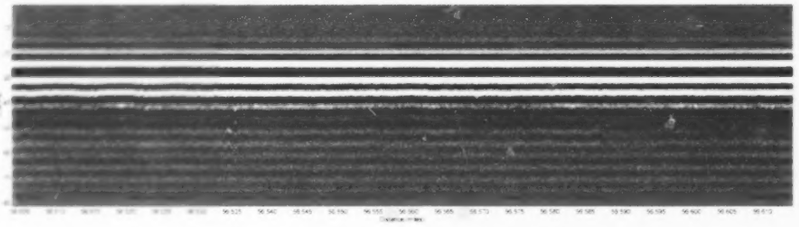


Figure 76c: Filtered Data

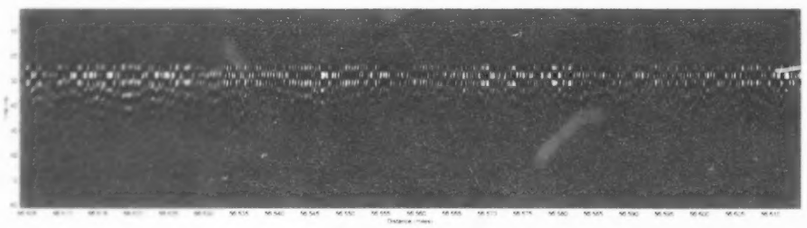


Figure 76d: Data after Average Trace Removed.

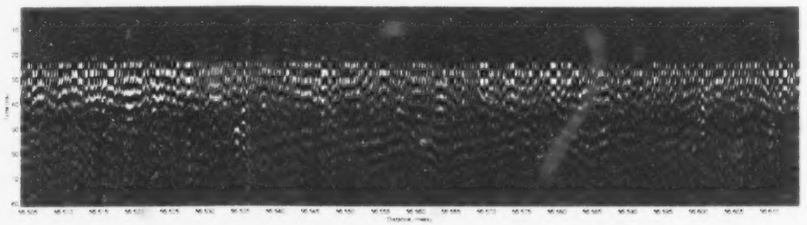


Figure 76e: Data with Linear Gain Applied

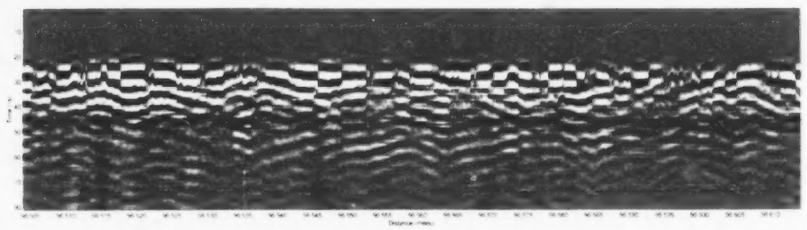


Figure 76f: Data with Linear Gain + Horizontal Filter Applied

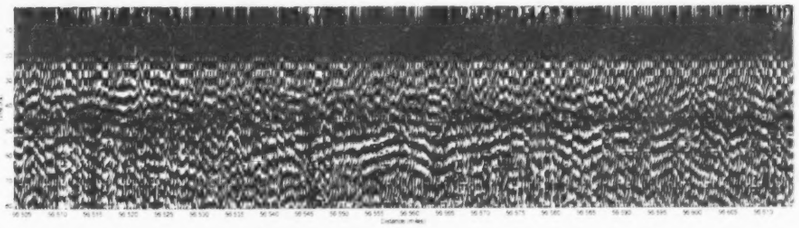


Figure 76g: Data with AGC Gain Applied

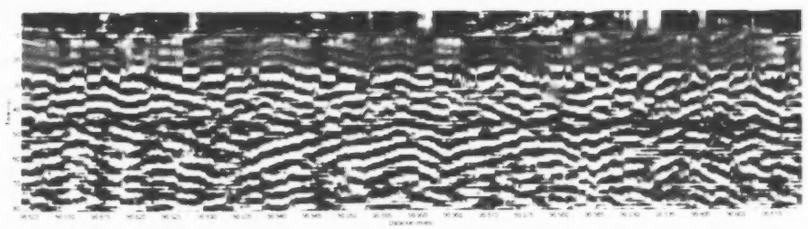


Figure 76h: Data with AGC Gain + Horizontal Filter Applied.

Ballast Investigation
Ground-Penetrating Radar
CN/CPR Rail Line, Ashcroft, B.C.

FIG. 76: Comparison of Processing Steps

CANADIAN
PACIFIC
RAILWAY

Queen's